FARM CROPS

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BY MANY SPECIALISTS

UNDER THE EDITORSHIP OF

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PREFACE

The Science of Agriculture, though amongst the oldest which have engaged the attention of mankind, is still subject to developments which call for alert consideration by the modern farmer, the aim of whose endeavours must ever be maximum economic production per acre.

The recent advances in our knowledge of Agricultural Science have been so considerable that I believe if we were to give effect, in actual everyday practice, to all the vitally important knowledge which has been gained by research and experiment, and tested by demonstration and experience, the result would soon establish confidence in the future of Agriculture in the Motherland.

It is highly desirable that full information regarding the principles underlying maximum crop production should be readily available. The publication of an up-to-date treatise on Farm Crops had therefore become a matter of the first importance.

The work is a comprehensive one embracing articles from forty contributors, all of whom have special knowledge of the subjects on which they write. Each crop is dealt with fully and separately, and allied subjects of importance in Plant Husbandry also come under review. The contribution from the late

Professor A. N. M'Alpine, B.Sc.(Lond.), A.R.C.S., on "Weeds of Arable and Grass Land", the last pronouncement of a great authority, is sure to be of peculiar interest to many readers.

The general aim kept in view in the preparation of the work has been the furnishing of full and up-to-date information on all matters relative to the successful cultivation of the crops dealt with, and the presentation of it in a manner likely to be appreciated by all interested in Agriculture.

The editor wishes to thank all those who have contributed or assisted in providing originals for the illustrations. He also wishes to express his personal indebtedness to Mr. J. W. Stewart, B.Sc., for helpful advice as to the scope of the work, to Mr. W. Riddet, B.Sc., C.D.A.(Hons.), N.D.A.(Hons.), N.D.D. (Hons.), for assistance and many valuable suggestions, and to Mr. A. F. R. Nisbet, M.A., B.Sc., N.D.A., N.D.D., for his very efficient work as sub-editor.

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LIST OF PLATES

THE DOMESTICATION OF PLANTS

By W. G. SMITH, B.Sc., Ph.D.

The domestication of plants began before agriculture itself. When man was a nomad following his flocks and herds from one grazing ground to another, as is still the case in Central Asia, there could be no intensive cultivation of the soil. Seed was carried from one camp to another, sown in roughly prepared ground, and harvested before the next migration; but it is probable that if any crop was better than another, the seed-corn would be taken from it. The hunters of the primeval forest depended for vegetable food on the herbs, roots, and fruits of the forest, and only acquired agricultural land after they formed settlements in forest clearings.

The development of resident populations was the beginning of land-tenure, and thence arose a peasantry whose main subsistence was derived from the land.

The earliest knowledge of cultivated plants comes from the ancient centres of civilization, but, in spite of much investigation, the record is still very fragmentary. There is evidence that the cereals—wheat, barley, oats, maize, rice, millets, and sorghums—were already under cultivation in prehistoric times. The root crops came later, and their domestication can be traced more easily. In the case of grasses and clovers, the cultivated forms are little removed from the wild plants, and the process of bringing these under cultivation is still in progress.

The first step in the evolution of a cultivated plant is to find a species that will be useful and so claim a place in the farm or garden, or as a medicinal plant. How one plant came to be cultivated, while so many others are left untamed, seems to have been partly a matter of chance. It is essential, however, that the wild plant will improve with better treatment. Experienced gardeners know that some plants will not "break the type", and that little can be done to alter the original form. There are many wild fruits in the forest, but not all of them have responded to cultivation like the apple, pear, plum, and cherry.

The early history of our cereal crops is so obscure that, in spite of much research, there is still doubt as to the parent forms. The lake dwellings of Switzerland date back to the Neolithic or later period of the Stone Age, before the time of the Trojan wars, and amongst the remains of these dwellings grains of wheat, barley, and other plants have been identified. This points to some kind of early cultivation, because wheat and barley are not wild plants in Switzerland. These remains also include several distinct kinds of wheat, which is evidence of considerable progress in the civilization of plants.

Egypt under the Pharaohs, in the time of Joseph, cultivated corn on a large scale, and was able to supply neighbours. Remains from ancient Babylonia (Mesopotamia), say 2800 years before Christ, have yielded two varieties of wheat, also four-rowed barley, and a recipe for making beer.

It is recorded that about the same period in China a yearly religious ceremony was instituted, which included the sowing every year of seeds of five plants—wheat, rice, sweet potato, and two kinds of millet.

In America the ancient civilizations of Mexico and Peru have left monuments which indicate the cultivation of plants like maize, tobacco, and sweet potato. This evidence points to a very early discovery of the parent forms.

The probable home of European cereals was the hilly districts of Western Asia, such as Asia Minor and the Caucasus; thence their cultivation extended into countries adjoining, such as Babylonia, Egypt, and ancient Greece and Rome, where men formed settlements and engaged in agriculture. China was another ancient centre where plants native to the land or introduced from adjoining lands were under cultivation. From centres such as these the cereals have been carried by man far beyond their original home, and cultivated wherever the climate is favourable.

The existence of many varieties of cereals indicates that the parent plants were variable in form. They are also adaptable as regards climate, for wheat, barley, and oats range from northern countries with a severe winter southwards towards the Equator, until prolonged periods of drought limit their extension. This adaptability arises from power of variation, so that races are obtained suitable to various degrees of heat and cold, drought and moisture.

The variability of cereals was known to writers on British agriculture a hundred and fifty years ago. Marshall, of Pickering, says: "In every field of corn there is as much variety as in a herd of cattle". Le Couteur, of Jersey, after collecting twenty-three distinct forms of wheat from a single field, sowed them separately, and in 1830 he placed on the market a new variety, Talavera de Bellevue, long a favourite English wheat. Shirreff, in East Lothian in 1819, found a specially vigorous plant of

wheat which he manured; it yielded sixty-three ears, and a few years later the progeny was distributed as Mungoswells wheat. By similar methods Shirreff raised a number of new oats.

The methods of the early improvers of cereals are still followed under the name of Selection. If a sample of common grain from any district be sown out, it will generally be found to yield plants differing in foliage and ear, in time of ripening, or in yield. A selection of the ears, sown in separate plots, will result in more uniform plants on each plot. In three or four years, if the plots are supervised and any rogues removed, the progeny will be a pure line, each plant closely resembling the other. The obtaining of pure lines of wheat and barley is simplified by self-pollination, so that ordinary pollination takes place before the enclosing chaffs open. Cross-pollination may take place later when the stamens emerge, but natural crosses have not been often observed. There is more risk of cross-pollination with oats, rye, and ryegrass.

Selection has brought about great changes in the races of cereals. The ancient wheats were mainly small-eared, with one or two grains in each spikelet; others were spelt wheats, with ears that break up into joints, and the grains do not thresh out of the chaff. These were suitable for spring sowing in Mediterranean climates, but under the conditions of Britain, Northern Europe, and North America they generally yield poor small plants. The northern farmer has shown a preference for varieties of common wheat which will yield heavily and mature in an average northern autumn. Autumn-sown wheat has almost displaced spring-sown, and the modern preference is a compact, square-eared type with red or white chaff and grain. There has been a considerable increase in yield. Cullam states that in England in the fourteenth century the ordinary crop of wheat was about a quarter to the acre, but often did not exceed six bushels. The modern average yield of four or five quarters may be partly due to improved cultivation, but all along there has been a steady selection of suitable varieties.

Hybridization has been often employed since Shirreff's time to assist selection. The crossing gives a stimulus to the production of new forms, from which may be selected types superior in some qualities to the parent races. Garton, of Warrington, has introduced numerous hybrids during the past twenty years, and several of these have proved successful in agriculture. Biffen, of Cambridge, has raised hybrids which promise to combine the special baking qualities of Canadian hard wheat with the larger yields of English wheats less suitable for baking.

Oats and rye are crops of relatively recent times, compared with the antiquity of wheat and barley. They have followed the civilization of Northern and Western Europe since Roman times. One of the wild parents of the oat varieties is *Avena fatua*, still found as a weed (see also article on Oats). The annual varieties of rye now in cultivation

are probably selections from a parent form which is still grown in Russia as a perennial crop.

The root crops of agriculture were civilized later than the cereals. The parent species of turnips, rapes, cabbages, and beets may still be found on the beaches and cliffs of the coasts of Europe, and in waste places inland. The chief condition for their occurrence is open soil not overgrown by grasses or shrubs. Sometimes the situation suggests that the plants are garden outcasts, but if so, it indicates that these plants quickly revert, so that they cannot be far removed from the wild forms.

The Wild Cabbage (*Brassica oleracea*) has an erect stem bearing leaves inclined to be fleshy, and sometimes crowded to resemble a poorly developed cabbage. The plants are frequently herbaceous perennials, and bear flowers for several years. The wild plant has little to distinguish it from many other plants, yet it has given rise to a multitude of forms. The one-headed cabbages vary in shape, colour, and wrinkling of the leaf. The kales have the leaves distinctly separated, do not form heads, and the leaves may be smooth or wrinkled (Scotch kale). The Brussels sprouts, with numerous cabbage-like buds; the cauliflower, with curious edible flowers; and the kohl-rabi, with its stem thickened to resemble a turnip, are all descended from the Wild Cabbage. These varieties are fixed and come almost true from seed, although there is an inherent tendency to show variation. They also hybridize after cross-pollination by insects, producing, as a rule, useless monstrosities, so that care is necessary to isolate plants grown for seed.

The turnip, swede, and rape belong to one or more prolific species of *Brassica*, distinct from the cabbage. Several forms of *Brassica* were known to the Romans as garden vegetables; their cultivation has been extended over all temperate countries, and the number of varieties obtained by selection has increased considerably.

The beet family has been equally prolific in cultivated forms. The Wild Beet (*Beta maritima*) occurs on the shores of Britain, Europe (including the Mediterranean), and the Canary Isles. The plants have a deep, much-branched, and perennial root system, somewhat swollen at the upper end of the root-stock, which bears a crown of greenish-purple leaves.

The cultivation of beet can be traced back to ancient Greek and Roman times, but the number of varieties has greatly increased, and now includes the various races of mangolds, garden beet, sugar-beet, and variegated foliage beets. These differ considerably in colour of leaf and root, from the deep purple of garden beet to the white flesh and green leaves of sugar-beet; all of them are cultivated as annuals or biennials. Since the end of the seventeenth century the sugar-beet has been much improved in size, texture, and yield of sugar. About

a hundred years ago the average sugar content was about 6 per cent, but, by careful selection of seed raised from roots tested and found rich in sugar, the average sugar content was raised to about 13 per cent in 1888, and in 1908 was 18 per cent; but 25 per cent has been found.

The early history of the potato indicates that it was already a cultivated plant in South America when introduced into Europe in the sixteenth century. Several species of tuber-bearing Solanums have been found wild in Chile and adjoining countries, and from one or more of these the numerous varieties of potatoes are descended. Improved cultivation, selection, and hybridization have each been employed, and the result has been a great increase in yield and size of tuber. On the other hand, flowering and seed production have received less attention, so that many modern varieties flower scantily and rarely mature seed.

The domestication of grasses and clovers is comparatively modern. Red and white clovers are natives of Britain, but when in the seventeenth century clover became a farm crop, it was varieties from the Continent which received attention. The efforts of seed-growers have resulted in considerable improvement in yield, hardiness to winter, and resistance to clover-sickness, but these and other qualities might still be further improved. In recent years Wild White Clover raised from native races has proved more productive in pastures and lasts longer than the older varieties, and attention is now being given to the merits of native or Wild Red Clover.

The increased sowing down of grassland with definite mixtures of pure grass and clover seeds has directed attention to the improvement of native wild grasses, especially Ryegrass, Cocksfoot, Timothy, Meadow Fescue, and Tall Oatgrass. If a collection of plants or seedlings be made from various soils and districts, considerable differences may be seen amongst plants of the same species. Selection and propagation of suitable parent plants may result in an improved race, more productive for hay, or better adapted to grow on various kinds of soil. The cultivation of Ryegrass (*Lolium*) dates from the early part of the seventeenth century. The wild plant is widely distributed in Britain and Europe, and where it occurs in old grassland it is distinctly perennial. Certain varieties, or species, native in Southern Europe flower vigorously in the year after sowing, and selections from these gave rise to Italian Ryegrass and other varieties more or less annual. The demand for Perennial Ryegrass led to selection, and early in the nineteenth century the merits of varieties such as Pacey, Russell, Whitworth, &c., were widely discussed. Other species like Cocksfoot, Timothy, Meadow Fescue, and Tall Oatgrass are now receiving more attention, notably in Denmark and Sweden. One result is that commercial grass seeds have been considerably improved as regards size and maturity, so that they germinate more uniformly. The variations

in growth amongst native grasses have led to investigations which promise to produce races suitable for special purposes, such as a tall, leafy, tillering race more suitable for hay, and a dwarfer, turf-forming race, resistant to winter and vigorous in spring.

The process of domestication begun so long ago in the cereals may thus, in the case of grasses and clovers, still be seen in progress. But what has been done for agricultural plants is meagre in comparison with the results achieved by the horticulturist. The demand for novelties has led to great competition, and even to-day explorers are searching remote parts of the earth for new wild plants to be domesticated by every possible device, including cultivation, propagation, selection, and hybridization.

THE IMPROVEMENT OF CULTIVATED PLANTS

By THOMAS ANDERSON, M.A., B.Sc.(Agric.)

Part I.—Historical Summary

Though historical records of the intentional preservation and multiplication of specially prolific examples of cultivated types of plants go back to the beginnings of civilization, there is no authentic information extant by means of which we can trace the successive stages of development of our commonly cultivated agricultural species, except that which refers to a period long after these species had arrived at a state little different from that in which we find them to-day.

Such definite records as are available do not go much farther back than a century, and refer merely to the finishing touches put on species by improvers in relatively modern times. The accounts which these improvers have left of their work indicate, to some extent, the general tendencies of the operations practised by many agriculturists independently, most of whom left no record of their doings except in their actual productions.

Thomas Andrew Knight was probably the first hybridizer of cereal varieties, and produced notably hardy varieties of wheat about the end of the eighteenth century.

The periods of bad harvests which marked the close of the eighteenth century and the early part of the nineteenth century appear to have awakened agriculturists in general to the necessity of obtaining improved varieties of all sorts of agricultural produce. The attainment of this end was attempted by two methods, namely by the introduction of new varieties from foreign parts and by the selection of varieties at home.

In the first half of the century John le Couteur and Patrick Shirreff were notable selectors. Le Couteur discovered the fact of the occurrence of hereditary differences among apparently similar forms of the same

variety, and isolated a large number of strains of wheat, each built up from the produce of a single plant. Several of these strains became popular commercial varieties.

Shirreff, like many other agriculturists of his time whose names are often associated with the varieties which they introduced, in his early efforts at improvement selected extraordinary plants as the starting-point of special varieties of wheat and oats. Long before the middle of the century the principle of multiplying a single plant selection in order to get an improved and uniform race was widely known and commonly practised by many members of the farming community, who found it a profitable way of increasing the yield of their crops. Some of these "foundling" varieties attained a wide popularity, and several still remain standard local varieties to-day.

Examples of cereal varieties developed from a single plant which are approximately a century old are: Potato Oat, Sandy Oat, Hunter's White Wheat, and Chevalier Barley. Attention was not directed solely to cereals, but both roots and grasses received attention. The credit for developing the turnip to meet the condition of the British climate has been allotted by various writers to Border farmers, who introduced improved husbandry to the cultivation of the crop about the middle of the eighteenth century, and who produced and maintained stocks which have been the foundation of the standard types. Perennial ryegrass was practically the only pasture plant on which improvement was attempted: selection of this species was directed towards obtaining varieties which would give a pasture sole of greater permanency than was attained by the use of ordinary commercial seed. In the early part of the nineteenth century several selected varieties were known, such as Pacey's, Russell's, Whitworth's, but these have been lost and with them any claim to pasture-permanency of the species.

Following the disastrous years of 1845 and 1846 for the potato crop, the improvement of the potato in respect of resistance to blight engaged the attention of William Paterson, whose variety Victoria became a standard type and has been utilized by Mr. Archibald Findlay and others as the foundation for many of the modern varieties of the species.

Subsequent to the middle of the century the work of improvement of cereals was continued by Shirreff, who, in his later years (1856–76), adopted the principle of selecting and comparing typical plants of standard varieties of wheat and oats for the purpose of obtaining the best types within these varieties, while still practising the search for foundlings. He also hybridized varieties of wheat, but the results of his attempted improvements on this basis were not successful, the lack of any important result being attributed by writers of the time to the use of non-hardy varieties such as Talavera in his crosses.

F. F. Hallett also practised the principle of pedigree breeding of cereals, but in a more intensive fashion than Le Couteur and Shirreff. He attempted to improve his initial selections by further selection aided by intensive cultivation.

In France the development of various cultivated plants was instituted by the Vilmorins, and Louis de Vilmorin practised the method of single plant selection of Le Couteur, which became known on the Continent as the Vilmorin method of improvement. In Germany numerous workers were engaged in the improvement of agricultural plants by the method of mass selection, which remained till the end of the century the principle adopted throughout the German Empire, where notable results followed the organized improvement of types of agricultural produce, associated as it was with improved husbandry and scientific manuring. For the period of thirty years ending in 1908, Germany had increased her average acre-yield of cereals by 50 per cent, of sugar beet by 40 per cent of sugar, of potatoes by 65 per cent, and of meadow hay by 8 per cent.

Towards the end of the century very important developments in the history of plant breeding took place. The developments are mainly associated with the work of the Svalöf Institute in Sweden, the organized operation of the State experiment stations in the United States, in Canada, and in Denmark, and the individual work of the hybridists: Henri de Vilmorin, in France, on Wheat; C. G. Pringle and A. E. Blount, in America, on Wheat; John Garton, in England, on Oats, Barley, and Wheat; Wm. Farrer, in Australia, on Wheat; and Dr. Wm. Saunders and C. E. and A. P. Saunders, all of whom were successful in producing useful hybrid varieties, and each of whom individually discovered the principle of eventual fixity of hybrid selections.

Mr. Archibald Findlay had remarkable success with hybrid varieties of potatoes, his Up-to-Date and British Queen becoming the standard varieties in Britain and retaining this position for a very considerable period.

Following on the rediscovery, at the beginning of the present century, of Mendel's law and the establishing of the usefulness of the pedigree pure line in improving varieties, the work of selection and of hybridization became standardized.

With reference to arable husbandry, some notable productions of the later years of the century were:

Garton's hybrid Abundance Oat and Standwell Barley;
Findlay's hybrid Up-to-Date and British Queen, varieties of potato;
Farrer's hybrid Federation Wheat (New South Wales);
C. E. Saunders' hybrid Marquis Wheat (Western Canada);
Dr. W. Saunders' hybrid Preston Wheat (Canada and United States);

all of which have become standard varieties in the areas for which they are suited.

The rapid developments which have occurred during the last two decades in the science and practice of plant breeding have had the result of introducing to agriculture many varieties of prolific and hardy cereals. The operations of the Swedish Svalöf Institute have resulted in the finding for Sweden of varieties of cereals specially suitable for all the variations of her climate and soil; several of these varieties have proved to be excellent "general purpose" varieties, as, for example, Victory Oats and Iron Wheat, which have become in this country candidates for the premier place in popularity. The Institute has, in addition to cereals, developed improved varieties of forage, root, and herbage plants to the advantage of every type of agriculture in Sweden. In Denmark the development of roots and grasses has been remarkable. This development has been attained as much by the encouragement of private enterprise in improvement of types as by scientific breeding at the agricultural institutions. The method of discrimination consists in public competitive trials of strains of roots and herbage plants at the various State agricultural stations, each trial being conducted for a series of years at several of these stations.

The excellent hybrid varieties produced by Garton's Ltd., especially of oats, have displaced many of the older standard varieties even in the areas for which local standard varieties, such as Sandy Oats, were suitable. Professor Biffen, of Cambridge University, has produced several remarkable varieties of wheat.

So far as barley is concerned, the feature of the latest developments has been the partial displacement of the Chevalier and Goldthorpe types by hybrids which carry the grain qualities of these types in combination with the hardier qualities of the Archer varieties, the special properties of which were first noted in Denmark, and have been developed in selections and hybrids by Mr. E. S. Beaven in England and Mr. H. Hunter in Ireland.

The development of the potato in Britain has been conditioned by the necessity of obtaining varieties resistant to wart disease, and has been greatly assisted by the work of the well-known Ormskirk Testing Station, which is now associated with the National Institute of Agricultural Botany.

In Canada development has been associated with the co-operation of the Dominion Experimental Farms—where breeding and comparative testing is carried on—with the Canadian Seed Growers' Association, the object of which is to maintain the purity and quality of standard varieties of agricultural plants, and to encourage the practice of growing selected stocks of these throughout the Dominion.

The greatest advance in scientific plant improvement in this century

has been that which has taken place in the Agricultural Experiment Stations of the United States, where a large coterie of distinguished scientists, organized as the American Breeders' Association and working with illimitable material, have developed the science of plant improvement to a degree unknown in other countries.

The movement for the organization of plant breeding for practical agricultural purposes has made a notable advance in these islands within the past few years.

In addition to those previously in existence at Cambridge and Dublin, there are now in operation plant-breeding stations at Aberystwyth in Wales and at Edinburgh in Scotland; while two stations, whose functions are to test and register new varieties of agricultural products, have been established, namely, the National Institute of Agricultural Botany, at Cambridge, and the Registration Station of the Board of Agriculture for Scotland, at Edinburgh.

A few examples of the improvement effected by scientific and organized effort will indicate the gradual advance which is being made. The successive stages in improvement of a species cannot be better illustrated than by reference to the statistical results of comparative trials of the various productions of the Svalöf Institute. Two of the varieties of wheat which earliest attracted the attention of Dr. Nilsson were the Squarehead and Grenadier types. The successive derivatives from these were:

Selected Squarehead (mass selected),
Extra Squarehead I (pedigree strain),
Extra Squarehead II (hybrid ex Squarehead × Grenadier),
Grenadier I,
Grenadier II (pedigree line),
Grenadier III (pedigree line),
Iron Wheat (hybrid derived from Grenadier).

In a series of trials lasting over five years, Iron Wheat gave a yield:

9 per cent above ex Squarehead II,
16 per cent above Grenadier II,
25 per cent above ex Squarehead II, and
40 per cent above Ordinary Squarehead.

Nor can the effect of systematic work in improvement be better instanced than in the result of the efforts in Sweden, where in the period 1889–1913 wheat production in the Malmö district was tripled.

A further example of the successive stages of advance which are the result of breeding is afforded by several varieties of rye, which have been accepted as the standard types on the Continent. For a quarter of a century or more the standard Continental autumn rye was Rimpau's

Schlanstedt, a mass selected sort; this has been almost entirely displaced by Petkus Rye, which is regarded as being a better yielder by 10 per cent. In 1901 a selection, Star Rye, was made from Petkus at Svalöf, and this is claimed by the Swedish station to have shown in comparative trials an 8 per cent increase in grain yield over the parent variety.

In Sweden the selected Crown and Victory varieties are regarded as the most successful oats produced by the station, and their wide popularity outside Sweden has proved their value. Crown is regarded in Sweden as superior to Victory.

Recent three-year trials in Sweden have shown that certain selected hybrids are superior to Crown, one of these being a hybrid between the two varieties.

The development of comparative tests in Denmark has raised the yield of dry matter per acre in mangels and swedes by 10 to 12 per cent above the average of crops derived from ordinary commercial seed of unspecialized strains. The system has also established the superiority of certain strains of herbage plants, for example, the Olsgaard strain of Cocksfoot, now largely represented in the exported Cocksfoot seed, which has the highest reputation on the seed market, and the Morso strain of White Clover, which in Denmark has proved superior even to English Wild White Clover in competitive trials.

As examples of the result of the less organized work in Britain may be cited the case of Professor Biffen's Yeoman Wheat, which is credited with the official record of having produced 96 bushels of grain to an acre, while the phenomenal yields of some of the Garton varieties are known to every reader of the results of the various Agricultural College Trials.

The testing of selections and hybrids against the commercial varieties from which they have been produced has been a feature of the work of improvement at experimental stations all over the world. Notable examples have already been cited in the case of the Yeoman and Swedish Iron Wheats, two varieties of wheats which have been tested in various centres in England and have proved equally prolific.

Another example is the wonderful hybrid Marquis Wheat, which, when tested against Red Fife in Canada over a period of eight years, showed yields which were higher than the latter by 13·5 to 38 per cent. Evidence of the possibility of greater advance in the development of herbage plants is furnished by the results of experiments carried out at Cornell University on Timothy, where the average productiveness of seventeen selected strains was estimated at 37 per cent above that of crops raised from commercial unselected seed, and by the tests of the Swedish varieties, Primus Timothy and Gloria Timothy, which in tests at Svalöf gave 12 to 20 per cent more green fodder than ordinary Swedish Timothy.

It must not be forgotten, however, that no matter how carefully field tests may be planned, they are almost invariably unreliable, because they can never meet every contingency. In the case of cereals they are useful enough for the determination of yield and straw hardiness, but it has been the experience of growers that the true measure of a value of a variety is that of the demand for it in the market-place. No matter how carefully comparative tests are made, it is very frequently found to be the case that essential disabilities have failed to be anticipated or noted. Thus we have examples of fine barley varieties which in certain seasons were too thin skinned to stand threshing, wheat varieties which were so open headed that they retained moisture too readily, oat varieties which measured themselves to too narrow a range of conditions, potato varieties which require too finely balanced an association of climatic and cultural conditions. These varieties have not been distributed without trial; they had the apparent possibility of successful cultivation, but they had not attained the balance of qualities necessary to ensure their continued acceptance. It is a practical impossibility to verify fully all the potentialities and weaknesses of a variety: it can only be judged in certain essential respects and thereafter be proved on the principle of " trial and error ".

In the voice of popularity, therefore, we find the true gauge of value. Measured by this standard, the important improvements which have been effected during the present century are outstanding.

Part II.—Variation

The possibility of producing improvements on existing species of cultivated plants depends fundamentally on the fact of the more or less plastic nature of individuals within the species. This plasticity is exhibited concretely in the diversity of forms recognizable in a species or variety, variations from the normal specific or varietal type, either induced by the effect of environmental conditions, or of intercrossing, or due to something innate in the plant itself. The variations which are the most noticeable to the casual observer are the variations in size, stature, and habit, which are the result of differences in environment, and which may be well illustrated by comparing those plants of a corn crop, which eke out a precarious existence on a bare knoll, with others in the same crop which thrive in conditions in which they are nourished to perfection. But closer observation will show that there exist between individuals differences which cannot be accounted for by differences of environment—essential differences, such, for example, as are to be found in height and strength of straw, stooling capacity among individual plants,

each characteristic of the same species and growing under the same conditions. Essential differences are, however, not always so easily recognizable as in the examples given, and the problem before the searcher after improved or desirable forms of any species is to devise methods of determining the nature of variations which exist.

Man's hand has been on many species for centuries, moulding and guiding them this way and that, by selection and combination of varieties, until the number of cultivated varieties of some species runs into hundreds. So far has this specialization and alteration gone, that in many instances either the original wild form has become completely lost, or no clue has been left by which to trace the cultivated form back to its prototype.

The natural selection exercised in the wild by the exigencies of situation, soil, and climate has also moulded many of our more plastic native species in different ways. Thus, in one of the latest catalogues of British native plants, there are 173 named subspecies and varieties of the Wild Bramble, and 114 named subspecies and varieties of the common Hawkweed.

A high degree of essential plasticity, exhibited in the members of a group, may possibly indicate that evolutionary history is still at work. Stability, on the other hand, may indicate that evolutionary history is complete; and it is generally conceded by botanists that the instability and capacity for adaptation, which is a feature of certain genera, and which is frequently associated with great specialization, is an indication of a later history than that of more stable genera.

Certain it is that the facts of geographical distribution of plants indicate progressiveness on the part of certain groups, e.g. the Compositæ and Gramineæ; and it is among the individuals in these groups that we find the tendency to variation very marked. But even within the progressive groups there are forms which have apparently completed evolutionary history. An example may be cited in Le Couteur's Bellevue Wheat, which was remarkable for its stability, in contrast to the original Squarehead, which has been of such remarkable plasticity that it has been capable of being adapted by selectors to all conditions of cultivation both in Britain and on the Continent.

The natural laws governing variation, despite all the evidence that has been produced since Darwin's time, are still obscure, while its causes are speculative.

Darwin, using the observational method of study of variation, and basing his conclusions on a great collection of ascertained facts, propounded the theory that species originated from a parental form by continuous variation in different directions, natural conditions providing the eliminating factor, extinguishing the unfit, and perpetuating the forms which are best supplied with the means of flourishing under the conditions

of life in which they are fortuitously placed. Similarly he concluded that, by continuous artificial selection of small variations in one direction, and under artificial conditions of cultivation, it is possible to modify a species along any avenue of adaptation required, and to perpetuate and increase the modification by the cumulative effect of this continued selection.

While the results attained by empirical workers would seem to bear out the truth of this theory, controlled researches into the nature of variation and the origin of new forms have so far failed to substantiate it, the results of these experiments having had the effect of modifying to a considerable degree Darwin's findings in the matter. Darwin accepted the fact of the existence of variation without making an analysis of its expression, beyond drawing a distinction between that form of variation, which is expressed in sudden wide differences and is commonly known as sporting, and the individual variations found everywhere among the organisms composing a species or variety; he included among continuous variations in plants, both those differences caused by environmental conditions and those that are caused through cross-fertilization (hybrids in the narrow sense), as well as other variations due to essential changes occurring in the process of recapitulation by reproduction from seed.

The recent modifications of his theory are based upon stricter analyses of the nature of variation, and are a natural outcome of the classification determined by these analyses.

The principal corollaries to Darwin's theory of the method of artificial selection are the theories of "mutation", advanced by De Vries, and of "pure lines", propounded by Johannsen.

Mutation.

De Vries made observations on a large number of species, his investigations extending over a long period of years. The results of his study, particularly of the Evening Primrose (*Œnothera Lamarckiana*), led him to the conclusion that new species originate, not step by step by gradual variation in one direction, but suddenly by saltation, and that they are stable from the commencement. Some of the forms which he found to spring from the parent species occurred a great number of times in successive years, and while some exhibited in their progeny resulting from self-fertilization constant differences from the parental forms, which are only large enough to give them status as distinct varieties, others were found to be separated from the parent by so wide a difference as to justify their classification as distinct "elementary species".

Some of the mutative forms discovered are vigorous enough to be regarded as capable of maintaining themselves in a state of nature, and may be classified as "progressive" species; others are to be classified as

“ regressive ”, differing from the parent by some character lost; others again are weak, and are classified as “ degressive ”; while a number of forms which do not breed true, but constantly on self-fertilization throw some forms indistinguishable from the parent species, are to be regarded as “ inconstant ”.

When some of these mutations are crossed with the parent form, they give hybrids which in their behaviour have resemblances to species hybrids.

Pure Lines.

While the problem that exercised the mind of De Vries was chiefly that of determining the origin of species, science is indebted to Johannsen for very definite information regarding the nature of variation within varieties of cultivated self-fertilized species, and, as many of the most important of our staple food crops, particularly cereals and pulse, are self-fertilized, the definite information elicited by Johannsen's experiments, supported by the experience of selectors in other fields, has a very great significance with reference to the improvement of plants.

The fact of relative constancy of isolated strains raised from a single plant had been accepted and utilized by earlier improvers of cereals, and was the practical principle adopted by Shirreff, Le Couteur, Hallett, Vilmorin, also by Hays in Minnesota, and by Nilsson in Sweden. It remained for Johannsen to establish the nature of the laws governing their principle.

Johannsen analysed the character of the variation exhibited by beans and barley, by maintaining from year to year the progeny of individual selected plants.

In the first place he found that within cultivated races of self-fertilized plants are to be found a large number of forms which are essentially different one from another in various particulars: in other words, he found it possible to distinguish forms within a variety, just as one can distinguish varieties within a species, or species within a genus. The degree of difference between these forms is not obviously marked, and one may require the help of mechanical methods to establish a distinction.

Further he found that the forms composing a variety were stable, in so far as the successive progenies of individual plants had an average value which did not differ from that of the original parent. Johannsen attempted to alter the average of particular forms, by selecting for propagation those variations which showed the greatest deviation from the normal, but found that this method of selection had no effect in altering the normal expression of the characters of which study was made.

In the case of beans, by continually choosing the heaviest beans in successive generations, he found that the fluctuations in weight of the

seeds of any plant were in correspondence with the fluctuations exhibited by the parental and grand-parental forms, and that the average weight of the seeds of any selection could not be increased by continuous propagation of the selection from the heaviest beans. He thus proved that there existed in self-fertilized species pure breeding strains or "pure lines", and showed that the produce of succeeding generations raised from a single seed of unmixed ancestry, while showing normal fluctuations, does not in its average conditions show any change from the average condition of the parent, and that selection of special types within a pure line is not capable of shifting the average expression of the pure line. Although unsuccessful in obtaining any changes in the character of a pure line by cumulative selection, he observed evidence of mutation, or sporting, both vegetative and seminal.

Mendel's Law.

Mendel's law of the nature of the combination of parental characters in varietal hybrids was published in 1865, but was neglected until 1900. The attention focused on it at that time and since has been of tremendous significance to the trend of scientific thought and experiment in the domain of heredity, and has had the effect of creating a subsection of natural science, the science of genetics, itself large enough in its scope to be considered a subsidiary science. This chapter is too restricted to give any adequate expression to the intricate ramifications of this science, even in so far as it applies to plants alone, but a short résumé of the elements of the law in its bearing on plant improvement is given, and the reader is left to the study of its various expressions and phases in text-books on the subject,[1] in which excellent bibliographies will be found directing the student to details of the mass of work which has been done during the past two decades.

The nature of the law in its elementary form can be best explained by an illustration of its application to a specific instance of a cross.

Colour may be taken as a frequent expression of varietal difference, and the following illustration of the behaviour of colour characters in a hybrid cereal may be taken as typical.

If a variety of barley with black glumes (i.e. the husks of the grain) be crossed with a variety with white glumes, or vice versa, the seed progeny in the first generation will consist entirely of black grains. Barley is normally self-fertilized, and if the self-fertilized seed of the first generation be sown, the plants derived therefrom will be plants carrying only black grains and plants carrying only white grains in the ratio of 3 black : 1 white. If the plants of the second generation be similarly self-fertilized, the

[1] See Bateson, *Mendel's Principles of Heredity*; Newman, *Plant Breeding in Scandinavia*; Babcock and Clausen, *Genetics in Relation to Agriculture*; Punnett, *Mendelism*.

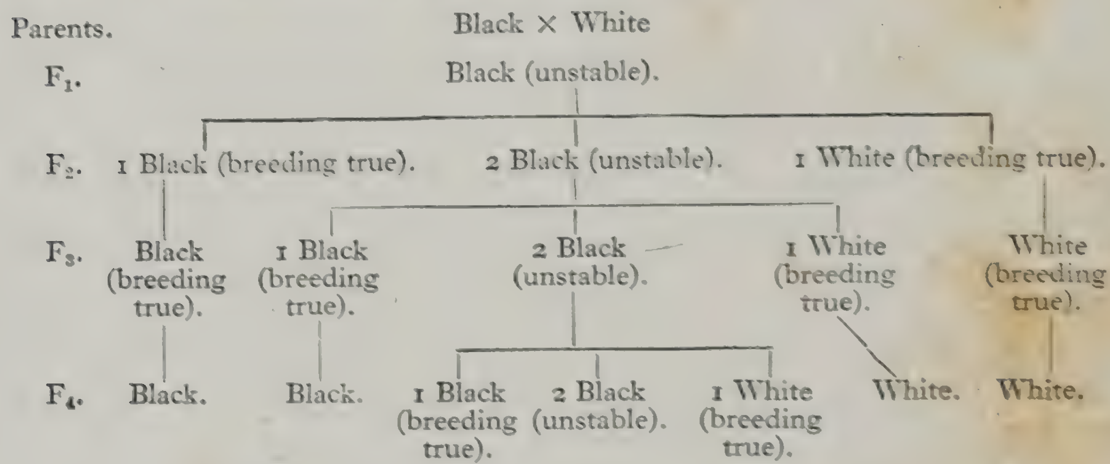
seeds of these plants will produce, in the third generation of the cross, plants according to the following ratio:

One-third of the black-grained plants will produce only black-grained plants.

Two-thirds of the black-grained plants will produce black-grained plants and white-grained plants in the ratio of 3 black : 1 white.

All the seeds of the white-grained plants will produce only white-grained plants.

The system of combination and segregation down to the fourth generation is shown in the following diagram; the letter F is the customary symbol used in Mendelian literature to indicate "filial generation", thus F_1 = 1st generation, F_2 = 2nd generation, &c.:



The black submerges the white character in the first generation and in all other derivatives of a mixed character, and is said to be "dominant": the white character is said to be "recessive". The resolution of derivative individuals back to the parental character and their tendency to breed true thereafter to that character is known as the phenomenon of segregation. The black segregates which breed true are known as "extracted dominants"; the white segregates are known as "extracted recessives", i.e. they are extracted pure from the mixed hybrid.

The explanation of the phenomenon of segregation is as follows:

A seed carries the characteristics of both parents, each parent supplying equal proportions. The sum total of the parental characteristics, generic, specific and varietal, morphological and physiological, are concentrated in the two reproductive cells which unite to give rise to the seed. In the case of the union of two reproductive cells of a constant form, be they derived from two individual plants or from a single plant, this union will give rise to a seed which will reproduce an individual resembling the

parents or parent in all essential respects, i.e. subject to the limits of normal variation, unless exceptional changes (sporting or mutation) are occurring.

If, however, two unlike forms are crossed, the hybrid seed resulting from the union will carry the characteristics of the two unlike forms in equal proportions. In the following generation the reproductive cells, before the incidence of fertilization, will carry the potentiality to reproduce any single character of either one parent or the other. Thus in the case of the illustration given above of a cross between black and white barley, 50 per cent of each set of reproductive cells in the first generation would carry the characteristic for the production of black colour and 50 per cent would carry the characteristic for the production of white.

The meeting of two reproductive cells being fortuitous, the character of the two cells which form any union is determined by the law of chance, and the possibility of combinations in the unions taking place between reproductive cells in the plants of the first generation of the hybrid are therefore as follows:

Black × Black	producing	Black	in the next	(second) generation	3
Black × White	,,	,,	,,	,,	
White × Black	,,	,,	,,	,,	
White × White	,,	White	,,	,,	1

From the nature of the combinations it will be seen that 25 per cent (Black × Black) and 25 per cent (White × White) will be constant, the remainder being inconstant and liable to segregate in succeeding generations in the same ratio as set out above. If, instead of being allowed to be self-fertilized, the F_1 generation be crossed back to the White the result will be as follows:

Black × White producing Black inconstants 2.
White × White producing White constants 2.

If it be crossed back to the Black the resultant unions are:

Black × Black producing Black constants 2.
White × Black producing Black inconstants 2.

Another example of absolute Mendelian segregation in Barley is to be found in a morphological difference which is utilized as a systematic distinction between varieties.

The base of the breast of a barley grain carries a small structure which is a continuation of the rachis or stalk on which the grain is supported. It is really a supernumerary node of the rachis and is termed the rachilla. The surface of the rachilla is in some varieties covered with longish hairs,

making the whole structure like a miniature brush, while in others it is covered with extremely short ones, and appears even under a lens as practically smooth.

The brush rachilla is dominant over the smooth, and the segregation of hybrid forms in the second and succeeding generations follows the same rule as is indicated in the illustration of the segregation of black and white colour given above.

If these two sets of characters are found in combination in two varieties thus—black with smooth rachilla, and white with hairy rachilla—and if the two varieties are crossed, the resultant first-generation hybrid will be black, and each seed will carry a hairy rachilla.

In subsequent generations these pairs of characters segregate independently of one another; consequently the number of combinations which may be obtained in the second generation is 16. The nature of these combinations can be best grasped by writing out the results of the combinations of each pair separately in quadruplicate, the one longitudinally and the other vertically, on equal squares of transparent paper, and transposing the one series of squares on the other. Thus the quadruplicate series of combinations for the colour pair may be written longitudinally thus:

Black (constant).	Black (inconstant).	Black (inconstant).	White (constant).
Black (constant).	Black (inconstant).	Black (inconstant).	White (constant).
Black (constant).	Black (inconstant).	Black (inconstant).	White (constant).
Black (constant).	Black (inconstant).	Black (inconstant).	White (constant).

The quadruplicate series for the rachilla character pair may be written vertically thus:

Hairy (constant).	Hairy (constant).	Hairy (constant).	Hairy (constant).
Hairy (inconstant).	Hairy (inconstant).	Hairy (inconstant).	Hairy (inconstant).
Hairy (inconstant).	Hairy (inconstant).	Hairy (inconstant).	Hairy (inconstant).
Smooth (constant).	Smooth (constant).	Smooth (constant).	Smooth (constant).

If now the second series of squares be superimposed on the first, all the results of possible combinations of the two pairs of characters will be shown thus:

Black (constant). Hairy (constant).	Black (inconstant). Hairy (constant).	Black (inconstant). Hairy (constant).	White (constant). Hairy (constant).
Black (constant). Hairy (inconstant).	Black (inconstant). Hairy (inconstant).	Black (inconstant). Hairy (inconstant).	White (constant). Hairy (inconstant).
Black (constant). Hairy (inconstant).	Black (inconstant). Hairy (inconstant).	Black (inconstant). Hairy (inconstant).	White (constant). Hairy (inconstant).
Black (constant). Smooth (constant).	Black (inconstant). Smooth (constant).	Black (inconstant). Smooth (constant).	White (constant). Smooth (constant).

Four constant combinations—one in each corner of the composite square—thus occur in the second generation, and represent in the aggregate 25 per cent of the total produce.

Two of these are the same as the original parents, but two, the black-grained form with hairy rachilla and the white-grained form with smooth rachilla, are new constant strains. The first of these is, however, undistinguishable from the constant black forms in this generation, but if all the plants were sown separately in the third generation the extracted dominants would be then distinguishable.

In the third and succeeding generations extracted recessives (white smooth) would again be obtained in the same ratio from the black (inconstant) hairy (inconstant) forms, but from those forms which are constant white and inconstant in respect of the rachilla character, segregation of the white smooth forms will take place in the monohybrid ratio 1 : 2 : 1.

The Multihybrid Ratio.

When more than two sets of absolute Mendelian characters occur in the parents of a hybrid, the number of combinations increase in geometrical progression and give a corresponding increase in the number of types. Thus, where there are three sets of such characters in question, the possible number of combinations which may occur is 64, of which 8 are entirely constant, 6 of the 8 being new forms, only 1 of the 8 being identifiable in the second generation, viz. the type combining the three recessives. When there are four sets of such characters the number of possible combinations is 256, 16 being constant, including 14 new forms, only one being identifiable in the second generation, viz. the type combining the four recessive characters.

When the parents of a varietal hybrid are distinguished by a high number of pairs of differentiating characters, there are thus great difficulties in identifying types, and the problem of building up by hybridization a new type combining a great number of characters may be a very intricate one.

Incomplete Dominance.

The difficulty is made greater by the fact that simple Mendelian ratios, such as are instanced above, are the exception rather than the rule. In the examples given, cases have been chosen where dominance is complete. But more frequently dominance is not absolute, and the second generation, instead of segregating definitely in the ratio 1 : 2 : 1, exhibits a series of types showing all gradations between the parent forms.

If a lax-eared barley be crossed with a close-eared type, the F_1 generation is intermediate in density, and only partial segregation takes place in the F_2 generation, the types appearing in this generation showing all

intermediate grades of density between the parental lax- and close-eared types.

The F_1 generation of a cross between a six-rowed and a two-rowed barley is similarly intermediate in respect of this pair of characters, and segregation in the F_2 generation is only partial. Only the end forms in this generation, i.e. those which have the botanical characters of the original parents, can be taken as having segregated in any degree of completeness, and even these apparently pure extracted forms would have to be tested for fixity in the event of the hybrid material being utilized for the purpose of making selections.

Other Modifications of Mendel's Law.

In addition to this exception to the law as originally stated, numerous modifications of the segregation process have been discovered by workers engaged in the application of the law to various species of plants and animals.

The feature of independent segregation does not always occur: in some forms it has been found that certain characters are always associated characters and are transmitted together. Sometimes this association is not complete, varying in degree in different segregates. These coupling relations are of very general occurrence, and have been found in a varying number of characters in various species.

Examples are known, too, in which a varietal difference carries with it effects which modify the whole character of the plant.

Sometimes the segregation of what is apparently a single pair of characters does not in the second generation show the ordinary monohybrid ratio of 3 : 1, but shows a ratio suggesting the dihybrid ratio, only 1 recessive being found in every 16 forms, or a trihybrid ratio of 1 recessive in 64 forms. Frequent records of the occurrence of this complex segregation in cereal hybrids have been made.

Occasionally the effect produced in segregation is cumulative, being an increase on the part of the segregate on the condition of its representative original. Thus when barleys are crossed, segregates to the close-headed type are frequently of greater density than the original close-headed parent. The case of a derivative of a hybrid oat being earlier than either of the parent forms has been noted at the Swedish station at Svalöf. Numerous instances have been recorded by hybridists of the appearance, in individuals of the progeny of a hybrid, of characters not represented in either of the parents. Examples of this appearance of apparently latent characters are found in cereal hybrids; for instance, white-grained varieties of oats and wheat have been derived from hybrids, the parents of which have both possessed coloured grains: examples of round mangels being derived from tankard forms have also occurred.

No absolutely definite evidence has been produced to show that the

Mendelian system of combination and segregation exists in the case of hybrids between species.

In species hybrids the F_1 generation is, as a general rule, intermediate in character, but sometimes this approximates closely to the character of one or other of the parents, generally to the maternal one.

There is, however, a very great practical difficulty in analysing the forms obtained by hybridization of species. In the first place, the F_1 generation is frequently self-sterile, and analysis of the mode of segregation can be obtained only by crossing the F_1 generation back to the parents. In the second, it has been already shown that the tremendous complexity of forms derived from varietal hybrids, which show considerable differences, renders analysis a very difficult matter. Thus if 10 different pairs of characters exist, and each of the characters exhibit strictly complete dominance and recessiveness, the possible number of different combinations in the F_2 generation will exceed a million. In order to get a definite analysis, it would be necessary to have several million individuals under observation. If several of the characters are intermediate in the hybrids, this practical difficulty is increased many times.

Then again, even an apparently simple character difference like colour may not be conditioned in the same manner in two forms in which the character is similar. This is particularly to be expected with regard to different species. The bio-chemical reactions producing the same colour in two different species may quite well be totally different reactions.

It can thus be understood that species hybrids may involve such a great deal of complexity in the expression of their segregation, that analysis of the products of hybridization is well nigh impossible.

But the occurrence of segregation in species hybrids has been proved in a modified degree.

The sterility of species hybrids appears to be generally due to the lack of development of the essential organs of reproduction, the imperfection appearing in failure to form pollen, or in the production of pollen which is weak and impotent, and in the production of imperfectly formed ovules. The weakness is generally greatest in the pollen: where self-sterility occurs, the hybrid can frequently be crossed back to both the original parents by utilizing pollen from them.

While hybrids produced between widely different species are frequently weak, hybrids between species possessing greater affinity are often very luxuriant, robust, and vigorous.

Classification of Variations.

The facts which have been elucidated by experimenters concerning the nature of heredity and variation are sufficient to explain the diverse character of individuals within a species or variety.

They serve to indicate the character of the deviations from the normal

which may be expected, and, by showing the many considerations involved, they emphasize the systematic attention to multifarious details necessary for the selection or creation of improved or desirable forms.

The types of variation which may be found in a species or variety may be classified according to the following scheme:

1. *Non-hereditary Variations.*—The normal fluctuations which occur in the progeny of a self-fertilized individual, but which in their average condition do not differ from the average condition of the grand-parental progeny, are non-hereditary. These fluctuating differences may not be entirely due to differences in environmental conditions, but may be inherent, i.e. while the variations themselves may not be heritable, the tendency to vary in this way may be heritable.

Non-hereditary fluctuations also occur in the progeny of cross-fertilized individuals which have the same hereditary composition. Sports are frequently non-heritable.

2. *Heritable Variations* may occur as small or large deviations from the parental character.

The mutations which De Vries found occurring in the Evening Primrose, even those that are unstable, are hereditary variations.

Any change which may affect permanently the normal expression of a single character, or of the sum total of the characters of a variety, is a hereditary variation. These variations may be quite minute and not nearly so obvious as fluctuating non-hereditary variations, which are due to the effect of environmental conditions. This has been shown to be the case in sugar beet. The differences between varieties with respect to average sugar content are quite small, and are exceeded by the non-heritable variations exhibited within each of the various varieties.

Among hereditary variations are also to be classed those differences which are conditioned by combination or segregation in hybridization of the characters of the individuals of dissimilar ancestry.

3. *Bud Variation.*—Mutations are not confined to changes occurring between one seed generation and the next. Indeed the most common form of sporting, as known to horticulturists, is vegetative in character. Bud variations do not always breed true from seed; neither are they always stable under vegetative propagation.

Part III.—Analysis of Cultivated Varieties—Selection and Pedigree Breeding

The selective material which is available for the isolation or creation of improved forms is the mass of the ordinary field crop, and, as a preliminary step to improvement, the knowledge of the nature of the material

to be utilized is a necessity. A field crop may consist of a decided mixture of two or more varieties of a species, or it may be tolerably or entirely pure and true to type.

A mixed crop may afford good material for selection, but, as a general rule, the selector prefers a crop which is true to type.

If the crop be of a variety of a self-fertilized species, such as wheat, barley, oats, beans, and peas, it may include, particularly if it be an old-established variety, a large number of distinct forms, which, while true in the main to the known type of a variety, yet differ in various ways from one another. The differences may be small, and not very apparent until examples are submitted to comparative propagation and searching analysis.

The forms may include the original type, along with mutations or sports which have arisen, and also segregates from chance hybrids between mutations, and even segregates from chance hybrids occurring through cross-fertilization with another variety. Most of these mutations (or segregates) will differ only slightly from the norm of the composite variety, but will exhibit fluctuations which will so grade one into another that the whole crop will appear to be of a perfectly even character. If the variety be an old-established one, there would seem to be no reason for the non-occurrence of cumulative mutation, which would appear to be in a modified sense what Darwin understood by hereditary continuous variation.

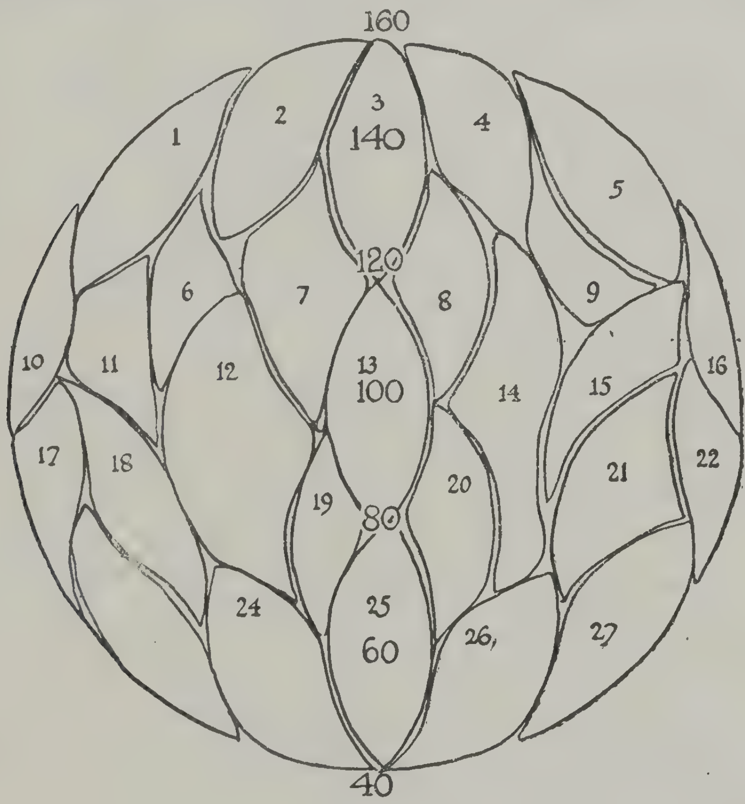
Most of the forms, if isolated, will probably be found to be constant. Even if there are forms which are derived from the result of cross-fertilization many of these will breed true. The Mendelian analysis indicates that unstable hybrid forms are in a few generations swamped by the extracted stable forms. Thus the result of segregation, in respect of a single pair of Mendelian characters, to the sixth generation is that the ratio of stable forms of the composition of the parents to unstable forms is 31 : 1. This ratio can be indicated graphically, thus:

Parents.
F_1. 1 × 1
F_2. 1 (stable) 2 (unstable) 1 (stable)
F_3. 2 1 (stable) 2 (unstable) 1 (stable) 2
F_4. 4 2 1 (stable) 2 (unstable) 1 (stable) 2 4
F_5. 8 4 2 1 (stable) 2 (unstable) 1 (stable) 2 4 8
F_6. 16 8 4 2 1 (stable) 2 (unstable) 1 (stable) 2 4 8 16

and shows that, in the sixth generation succeeding the cross, stability of the individual forms will be practically re-established, in respect of characters which follow the simple Mendelian rule of segregation.

In the case of characters which are intermediate in the F_1 generation, segregation back to stable forms will take longer, but ultimately stability will be restored.

In a composite collection of individuals, such as make up the mass of any well-established variety, one may thus expect to find a great number of forms which are stable, leaving out of account admixtures which are not true to type of the variety; these stable individuals being indistinguishable in their main morphological features from the typical form of the variety, but having an heritable average expression, which,



in respect of one or more characters, differs in greater or less degree from the average expression of the variety, and also from the average expression of the other individual forms making up the composite variety.

The character of such a crop may be diagrammatically represented by a circle broken up into mosaic, the circumference of the circle representing the range of the variety taken in bulk, and each individual mosaic representing the range of the stable or unstable strains of which it is composed.

In this diagram the numerals 1 to 27 indicate the various individual types making up the composite variety; the numerals 40 to 160 may be taken to represent the value of each in respect of any single character, or in respect of an aggregate of characters.

If the crop be of a species which is commonly or necessarily cross-

fertilized, e.g. turnip or mangel, one may expect to find a greater range of variation in the types composing the crop, because if there are differences brought about by cross-fertilization in the individuals composing the variety, it will be continuously in an unstable condition.

Selection and Selective Methods.

The selective method of plant improvement is the simplest, most largely practised, best known, and, even to-day, one of the most profitable means of obtaining improved forms.

A percentage of the variations which occur in a crop show an advance on the average of the variety, and the aim of selection is to isolate and propagate these, and from them to obtain composite and pedigreed strains which, in competition with the original variety, would prove superior in general qualities or in one particular characteristic.

The method of improving a variety by the selection of composite strains is known as mass selection; that of building up a strain from a single plant is known as pure line selection or pedigree breeding.

The practical details of the method to be employed in selecting within any species are determined by the usual mode of propagation of the crop in which the desired improvements are to be attempted. When propagation of the species is always by means of seed, the arrangements in the floral mechanism for fertilization have an important bearing on the method to be employed.

Reproduction in plants has as its essential feature the union of two cells, one of which carries to the progeny of the union the paternal characters, while the other bears the features which are maternal.

The organs of reproduction are found in the flower; they are generally the innermost whorls of flower parts. The showy parts are non-essential, though frequently accessory to the act of fertilization.

The organs bearing the reproductive cells are the ovary, which is usually the innermost part of the flower, and the stamens, which compose the next innermost whorl.

The ovary bears within it the ovule or ovules, which on fertilization become the seeds; the anthers bear the pollen grains, which are the paternal cells of the union.

Fertilization is effected by the transference of the pollen grain to the receptive surface (the stigma) of the ovary, by the germination of the pollen grain and its passage through the tissues of the ovary to an ovule, and finally by the fusion of the contents of the pollen grain with the ovule.

Union does not occur promiscuously among plants: pollination is only effective in consummating the union of the pollen cell and the ovule of plants nearly related. This affinity does not go beyond the bounds of a genus: species hybrids are frequently obtained, but generic hybrids are rare.

Thus if a species be normally self-fertilized, protection of the flowers from extraneous pollen may be regarded as superfluous, except for critical scientific work; the main precaution necessary to ensure purity of product is against admixture in the seed-bed. But, in the case of plants commonly cross-fertilized, careful protection of plants at flowering time from the effects of extraneous pollination is necessary, in addition to perfect isolation. The degree of protection to be given is to be considered in relation to the agents of natural pollination.

Species having dry, floury pollen have to be protected against wind-borne pollen as well as against the intrusion of insects.

After first selection has been accomplished, and the first harvest procured, the bulk of material on hand may be so considerable as to rule out the practical possibility of individual protection.

Recourse must then be had to massing in an isolated place to ensure that cross-pollination takes place only between individuals of the same original selection.

The species in cultivation in Great Britain whose produce forms staple foods are nearly all self-fertilized. The cereals except rye are self-fertilized, and the leguminous seed species, pea, bean, &c., are also self-fertilized.

Thus a special pure strain of any of these species can be established by the selection of a single individual plant, and the isolation and multiplication of its produce, unless the selected plant proves to be hybrid in origin and mixed in character. In the case of the latter, the produce derived from it will not be of one type, and will readily show under analysis that a pure strain has not been obtained.

The success of the policy of the older selectors, supported by the experience of modern improvers in many countries and placed on a scientific basis of certainty by the critical analyses of Johannsen, shows that the isolation of pure breeding types by simple selection offers good prospects of effecting improvements.

The experience of selectors in all parts of the world is that within the commercial varieties there are to be found types which, if isolated, are superior in various respects to the average of the variety, though true to its type, and which will breed true to the condition for which they have been selected.

Method of Pedigree Breeding of Self-fertilized Species.

Pedigree breeding or pure-line selection is a method of obtaining new and advanced forms by a system of isolation and comparison. It is based on the assumption that variation is constantly in operation and that it is ubiquitous, and that, consequently, in a variety which has been long established, there are forms which are true to the type of the variety, but distinguished from it in having an average condition, in respect of

one or more particulars, which is an advance on the average condition of the variety. There is the further assumption that these forms are stable, and that, while they are subject to variation, variation will be a relatively slow process, and will not disturb the uniformity of the strain for a considerable period.

A common method of procedure in making first selections is to select either exceptionally developed plants of the type which is characteristic of the variety selected for the improvement, or specially striking plants without reference to their botanical similarities to the mass of the crop.

The eye is not always a trustworthy guide. The method of selecting exceptional individuals has given place at the Svalöf station to a method of choosing for comparative test well developed average specimens of the variety, it being found that more advance could be obtained in this way, as many of the apparently exceptional types proved to be merely fluctuating variations of types whose average expression did not indicate any superior quality.

Selection may begin with the seed, and, while this starting-point does not afford the same opportunity of comparative judgment as is obtained by reference to plants, it is a useful commencement in cases where facilities for extensive cultivation of varieties are not available.

Mass selection is a useful preliminary to pure-line selection as it exercises a preliminary elimination of the unfit. While haphazard selection may produce useful strains, it may also load the selector with a great mass of material which will occupy time and space uselessly. The formulation of a basis of selection is necessary, and this basis should be founded on an intimate knowledge of the failings and virtues of the variety in which improvement is desirable, of the general performance of commonly cultivated varieties, and of the needs of particular districts in relation to climatic and other conditions.

Isolation and Comparison of Selections—Tests of Performance and Stability.

Primary selection having been made, this is followed by sowings of the seeds from the selected plants in such a manner that a fair preliminary test of the performance of each selection may be made. At the same time the degree of stability of the selections in respect of uniformity to type can be determined.

Each selection is grown in a small plot by itself or in a separate row. For purposes of comparison there must be also similar plots or rows of the variety from which the selection has been taken, and of standard commercial varieties which fulfil a similar purpose in cultivation. Comparison with commercial varieties of all kinds is especially necessary in trials of selections from old varieties which are almost or entirely out of

date, and which may only be retained in isolated places through sheer conservatism.

Whatever may be the basis of selection, the test must always be a test of relative general excellence as well, and must for this reason be continued for more than one generation.

The purposes of selection being the isolation of new strains from a commercial variety and the establishing of superior forms, it is necessary that the selected strains should be uniform in character, not only in strictly botanical features, but also in substantive characters.

The preliminary test will give a fair indication of uniformity of botanical characters, and will, in particular, give opportunity of eliminating hybrid forms which are still in process of segregation.

Want of uniformity in botanical characteristics may generally be considered as indicating lack of uniformity in other directions. Uniformity in substantive characters is a characteristic which can only be discovered by very careful attention, in further tests, to details of the multifarious considerations of difference in soil, effect of injury by insects or disease, climatic conditions, and other particulars, all of which must be carefully and systematically noted. Without this, a judgment of the relative superiority of selected strains, over the parental or other established varieties, is impossible. As examples of matters of substantive uniformity which ought to be noted in cereal strains are braird, stooling propensity, time of flowering, time of ripening, strength of straw, yield, and quality of produce.

The result of two seasons' growing at most is sufficient to establish fairly the matter of uniformity of type in botanical characters, as well as to show, from a negative standpoint, if a selection has claims to distinction; for although seasonal, climatic, and soil conditions are diverse, and may affect results to the prejudice of a true judgment, a two years' test in good soil will indicate obvious weakness in many of the selections.

The basis of elimination being unfitness in any one particular, obviously weak strains should be rigidly discarded, unless any one shows such excellence in one direction that it may be considered a fit subject for combination with another by hybridization. Ruthless rejection widens the basis of selection: retention of specialities is apt to end in a collection of failures.

After elimination of the weaker sorts, the remainder are tested again in the same fashion, and at the same time, in larger plots, similar plots of standard varieties being grown alongside these for purposes of comparison. Several years' testing of selections is necessary in order finally to retain only the best, and this testing is carried out in plots, the size of which as commonly standardized in many centres is $\frac{1}{200}$ of an acre.

With the accumulation of information on each selection the test

becomes more and more critical, and the final selections retained are usually small in number. The yield test is the final and most critical.

The variety or varieties to be tested are sown out, along with controls whose capacity for yield is known, by means of a seed drill, in parallel rectangular plots, the standard size of which is $\frac{1}{80}$ acre, each variety being repeated at least eight times. The plots which are allotted to a particular variety or selection are distributed in such a manner that each is at the maximum possible distance from all the others containing that particular variety or selection. Distribution of plots in this fashion ensures an equalization of cultural conditions for each sample tested. At harvesting the outermost rows of each plot and a portion at each end are discarded, and computations of yield are based on exactly similar rectangular portions of the crop of each variety under test.

Much attention has been paid, particularly by American investigators, to the methods of obtaining reliable information on yield from the results of field tests of this kind, and particularly to the rules to be followed in assessing and making allowance for differences in results between plots of the same variety.

Selection in Species normally or frequently cross-fertilized.

Selective methods of raising pure lines applied to the extraction of strains of plant species, which are propagated by means of seed and which are normally cross-fertilized in any degree, must naturally be much more careful than those applied to self-fertilized species. If the degree of cross-fertilization is very small, the ordinary pure-line method may be followed, but careful judgment and observation would have to be applied to the removal of forms not true to type. But in the case of the root crops, of which mangel and turnip are the most important, the degree of cross-fertilization is always large. The commercial stocks of seeds of these roots are always more or less mixed. In the case of mangel, mixture of a stock can sometimes be detected by germinating a sample of the seed clusters, as the young plantlets show differences in colour. The fact that one has to assume that the stock is mixed, coupled with the fact that cross-fertilization is likely to take place, makes it a difficult matter to obtain strains which will breed true. Further, in the case of species commonly cross-fertilized in nature, inbreeding may result in loss of vigour.

It is almost certain that original selections from root crops such as turnip and mangel are heterogeneous in character and unstable. In order to produce pure lines, self-fertilization as between flowers of the same plant is essential. Hence very careful guarding of the flowers from extraneous pollen is necessary, and if artificial pollination is carried out, it has to be done within doors to obviate risk of wind-borne pollen. This process of self-fertilization would have to be continued over a series of

years in order to obtain pure breeding individuals, by reducing the number of unstable forms. This reduction would take place automatically if the differentiating characters involved in the original heterogeneous individual segregated according to the law of Mendel.

Unless the basis of selection is narrow, i.e. applied to one or a few particular characters, it is possible that little improvement will be gained by establishing pure lines in varieties of roots. The accepted standard basis of selection for turnips and mangels is the percentage of dry matter, and it is on this single basis, in conjunction with uniformity of botanical characters, that a great advance has been made, in Denmark particularly, towards the perfection of both the turnip and the mangel.

Selection applied to Herbage Plants.

The application of the principle of single selection to herbage crops presents at first sight difficulties which look insuperable, and, in view of the immensity of these, experimenters have been slow to undertake work which gives so little promise of results.

The difficulties confronting the improver of such plants as the cultivated grasses and clovers, which are the constituents of hay and herbage, are associated (1) with the diversity of character of the selective material, namely the various species of grasses and clovers, (2) with the fact that there are two classes of producers to cater for, the seed farmer and the farmer who is utilizing the herbage, and (3) with the technical difficulties of isolating and maintaining uniform strains.

At one period there were distinct strains of Perennial Ryegrass on the market, such as Pacey's, Whitworth's, Evergreen, and Orkney Ryegrass, and lately some commercial firms, which make a speciality of improvements, have been working towards a greater degree of specialization in these products. Thus there are on the market special strains of hybrid Red Clover and White Clover, various types of perennialized Italian Ryegrass, and a quick-growing variety of Italian Ryegrass known as Western Wolths.

But while, in the more specialized forms of produce, specialization has had the effect of making the species cultivated in one area unsuitable for cultivation in another, and has therefore restricted the trade in seeds of root crops and cereals, and in seed tubers of potatoes, to territorial limits, *any variety of seed from any place within the limits of the globe is regarded as suitable for the production of hay and herbage.* There are climatic, economic, and other conditions involved in accounting for this state of affairs.

The English clover harvest is very uncertain, and it is only occasionally that the seed trade can supply a large proportion of home needs from home sources.

The popularity and undoubted value attained by Wild White Clover

in recent years serves to show the importance which may attach to home-grown seeds of indigenous species, and the vast possibilities which may lie in more careful attention to the smaller herbage plants.

At present the interests of the seed farmer and the grower of mixed herbage are not in common: the seed farmer requires yield of seed; the farmer who is the producer of fodder has to be content with what the market supplies him. The ultimate value of improved forms will only show in crops of mixed herbage, and any improvements will have little interest to the seed grower unless they effect an increase in the yield of seed or create a demand that will make their production a paying proposition.

The technical difficulties which lie in the way of isolating special forms from which to produce seed stocks are associated with the fact of cross-fertilization in nearly all the herbage species. Practically all the grasses are cross-fertilized, and while some of the leguminous species are capable of self-fertilization, cross-fertilization always takes place to an extent which makes it necessary to consider them as normally cross-fertilized. The difficulties are the greater because there are no means of getting selective material which can be considered reasonably uniform, as can be obtained in crops like mangel and turnip. Each of the species in any particular locality is a mixture of varieties and types. Lindhard states that in some species the diversity is great, as in Cocksfoot, in others the whole species approximates to a uniform type, as in *Poa pratensis*. The fact of this diversity, coupled with the occurrence of cross-fertilization, makes it probable that most of the forms to be found are in an unstable state, and consist of segregating forms and recombinations. Fixation of any form therefore involves the multiplication of the selection by vegetative propagation, the ensuring of self-pollination in the sense of its occurring between plants originally from the same crown, and the similar propagation of plants from the seed thus obtained, this being continued through several generations until a degree of fixity is attained in the final forms.

The multiplication of strains after fixation also presents great difficulty, as the pollen of grasses is wind-borne, and there is probably no place in the temperate zones where a grass plant could be cultivated out of reach of the pollen of the same species. Recourse must therefore be had to bagging the flowering heads in pairs until a sufficiency of seed is obtained to sow an area large enough to make the risk of undesirable fertilization relatively negligible.

The difficulties attendant on the selection of fixed forms from heterogeneous species have led to the devising of ingenious methods of ensuring self-fertilization within a selection. At Tystofte (Denmark) there is practised a method of getting selfed seed of clovers, by which a single plant is allowed to propagate itself vegetatively and protected, when

flowering, from the visits of insects by means of bee-proof wire-netting, controlled bees being then introduced to pasture on the clover and to carry the pollen from flower to flower.

Perfect uniformity in any variety of these cross-fertilized species is hardly possible, but careful work on the lines indicated above ensures the possibility of isolating forms which are uniform in producing from their seed plants notable in vigour and yielding capacity. As most of the herbage plants are perennials, the difficulties are at an end with the establishment on any considerable area of the approved selection, as this will yearly produce the stock seed necessary for its multiplication.

In spite of the difficulties associated with the selection of grasses, notable results have been obtained, particularly in selecting Timothy for rust resistance and high yield, at experimental centres in the United States, and in selecting Cocksfoot and other grasses in Denmark and in Sweden. Developments in the direction of the improvement of herbage species promise to be a feature of the activities of the new Welsh plant-breeding station at Aberystwyth.

No single general principle of selection can be rigidly followed. The conditions of variability and heredity and the nature of the objective determine the line of choice.

While many of the desirable qualities, which are made the basis of selection, are of such a kind as to make judgment of them a matter of mathematical estimation, there are others to which empirical standards must be applied. Some of the merely botanical characteristics can be judged by the eye alone, and their relative unimportance does not generally require that they should be examined in great detail. These characteristics are utilized as distinguishing marks, and when they have fulfilled this purpose their usefulness ceases. The important features of a grain crop are uniformity in braird, in length of straw, in strength of straw, in stooling capacity, in weight of produce, and in quality of grain. These are characters which can only be thoroughly well estimated by reference to a mass of the plants, when grown as an ordinary crop, and careful yearly notes on each selection are necessary to determine yearly averages in terms of these qualities.

Where immunity from disease or capacity to withstand unfavourable climatic conditions are qualities desirable, selections may be determined by exposing the selective material to adverse conditions of disease or weather. These methods, however, are more methods of mass selection than of single plant selection.

Selection and Disease Resistance.

Where stocks are pure and uniform in character, and true to type, the degree of resistance should be uniform throughout the variety.

The hardier varieties which resist disease are frequently undesirable

in other respects, especially in their capacity for yield, and, while a selection is capable of yielding hardy resistant strains, it is probable that these strains will be only moderately prolific. As a general rule, the problem of obtaining resistant varieties is approached by hybridization, selection being merely a preliminary step.

Selection applied to the Potato as an Example of a Crop propagated vegetatively.

In nearly all species varieties are known which have the power of resisting specific diseases, this power of resistance varying between absolute immunity and a power to thrive in spite of infection or attack.

In relation to resistance to insect attacks, examples of this are found in the American vines, which are resistant to Phylloxera; in varieties of oat, which are able to overcome frit-fly attacks; in relation to resistance to fungoid or allied diseases, immunity to the dreaded wart disease is believed to be absolute in the case of a considerable number of varieties of potato; resistance to finger-and-toe is a quality of certain selected varieties of turnip and swede; and resistance to rust and smut a property of certain varieties of cereals and selected strains of grasses. Regarding constitutional and other troubles, certain varieties of potatoes are not liable to cracking, hollowness, deadness of eye, sprain, leaf curl, leaf mosaic, and rust, which in other varieties are prominent weaknesses.

On first consideration, one might surmise that little hope of betterment could be obtained by selection of what is only a derivative part of a single plant; but critical comparative work in Sweden, in the United States, and in Canada has demonstrated at least that varieties of the potato can be maintained in a state comparable with their original degree of excellence by this means, selection acting probably in a negative fashion by eliminating weaker strains. The careful attention paid to selection of stocks by the most reputable commercial firms, especially those which cater for a garden trade in seed potatoes, indicates that a considerable amount of improvement may be possible, and that the maintenance of a high standard for a variety can be procured by selective methods. Many of our popular varieties were, on production, coarse and robust, with little to recommend them save their high yielding capacity, but, after extensive cultivation, have become finer in quality and appearance. In time the stocks deteriorate. It is well known that degeneration of stocks takes place if grown too frequently in the same locality, and this is probably due to the weakening of the stock by constitutional diseases like sprain or leaf curl. This degeneration would be to a great extent obviated by regular selection of stock roots.

In addition to the feature of deterioration in varieties, however, actual diversity of tubers is known to have occurred in a number of varieties, not only the fluctuating variation which is obvious in the shape of the

tubers at a single haulm, but diversity of shape, colour, and depth of eye, which are permanent characteristics of the produce derived from the different types of tubers. Colour sports, being obvious, are, of course, most frequently noted; other sports probably pass unnoticed, lost in the mass of the crop. There is no doubt about the occurrence of these sports in potato, though they are probably infrequent. They are doubtless of much the same kind as are familiar to the horticulturist in geranium, dahlia, rose, and a host of other species.

There is no reason to think that substantive sports in the direction of high yield and greater vigour might not occur, and the experiments, which have been made at the various experimental centres mentioned above, point to the possibility of actual improvement of the yield of a variety. These experiments took the form of a test of crop grown from seed potatoes from vigorous high-yielding roots, against the crop grown from potatoes of similar size from weak roots, and the results, in all cases, showed a much higher yield of produce for the derivatives of the vigorous stocks than for the derivatives of the weaker roots.

The multiplicity of varieties which approximate to the type of standard varieties, such as Up-to-Date, British Queen, and Sutton's Abundance, and the almost ubiquitous duplication of other popular varieties, indicates a certain degree of selection as a trade practice.

Selection within Pure Lines.

The pedigree method of selection has its basis on principles which were proved to be scientifically correct by Johannsen in his work on pure lines. A pure line is the progeny of a stable self-fertilized form. Hence intensive selection within the bounds of a pure line cannot logically result in further improvement. The practical application of the pure-line idea bears out this theory: the stability of pedigree selections shows it to be a practical working hypothesis. The fact of fertilization being the union of reproductive cells which are similar in their potentiality as carriers of parental characters, makes the seed produced of hardly greater significance in propagation than the vegetatively reproducing part of a perennial.

The possibility of improvement by selection within a pure line lies in the chance of isolating a transmissible variation or mutation. Johannsen has shown that mutations do occur within pure lines, and De Vries isolated them generally in many species. No scheme of improvement on a systematic basis could be applied to searches for mutations within pure lines, owing to their fortuitous appearance and the infrequency of their occurrence. Desirable alterations in type can be more readily produced by hybridization.

In old varieties, however, it is probable that there may be an accumulation of such transmissible variations, and, for that reason, old standard

varieties should not be allowed to go wholly out of existence and be entirely displaced by new hybrid forms.

Mutations or Sports.

The sudden appearance, in various species of cultivated plants, of individual wide variations which were not known previously to exist, is explained in common parlance by the term "sporting". Sports are known in a very large number of cultivated species, particularly colour sports among horticultural varieties cultivated for showy flowers.

The term "sport" is a convenient general one, but it is obvious that the so-called sports which occur in seedlings of annual plants, and those which occur in perennial plants as bud sports, are very different in nature.

The description is generally applied to a form which is obviously distinct from the parental form from which it has arisen, whether the differences between it and the plant of origin have a hereditary value or not. Mutations in the sense of the word as applied to sports indicates the tendency in plants to heritable variations in any degree.

The origin of many of our cultivated varieties of cereals has probably been due to the sudden appearance of diversity in an individual, and it is likely that the new forms, established as cultivated varieties by the early improvers, and indeed by modern exponents of selective methods in the same field, have originated as mutations in the same way as de Vries' new Evening Primroses are supposed to have done.

It is, of course, possible that these selections may have been the results of combination by chance hybridization.

Heritable changes which are expressed in the individual as differences from the parental form from which it has been derived, differ in nature and differ in degree. They may be changes in morphological characters or they may be distinctly physiological. They may be stable or they may tend to segregate back towards the parental type: instability appears even in bud sports. The differences may appear first as changes in the vegetative tissue and may be transmitted by seed produced from the sport, or they may be noticed only in seedlings, in which case the change is commonly assumed to have taken place in the seed.

Bud sports are very frequently associated with highly cultivated and highly specialized varieties, and occur particularly in varieties developed by hybridization.

Sports are not necessarily improvements on the varieties from which they spring. More frequently they are degenerates or monstrosities. But mutation takes place in desirable directions as well. The newer phases of selection have, as their basis, a search for forms with distinct heritable improved qualities. The older method of selection was to take out what was particularly striking to the eye; the new method or

line selection, as it is termed, subjects average forms to examination, propagation, and analysis. In attempting to isolate useful hereditary variations, the best field for investigation is assuredly the varieties which have been long in cultivation, and which are still judged to be of considerable value. But even the older varieties which have gone out of fashion might yield useful forms in areas where these old varieties are still cultivated. Essential heritable variations are probably not of frequent occurrence, and may not be readily noted in newer varieties. They are certainly not of the frequent occurrence suggested by Darwin. The application of the principle of mass selection to cereal varieties in Sweden, in the course of a few years, resulted in the extraction of the best variations that had appeared in these varieties during a century or more, and the system then became unprofitable because it was working faster than variation was occurring.

There is little doubt that the production of advanced selections from among the annual cereal grains will become limited in a short space of time, for varieties in all countries are being sifted thoroughly by a large number of interested investigators, and their efforts will very rapidly take out the best that is to be got. Fortunately, an avenue for further advance lies along the line indicated by hybridization, the practice of which should ensure the continuous production of varieties remarkable for their excellence, combining as they will do the best features of the productions of the selectors.

The theories of mutation and of pure lines are inadequate to explain the methods adopted by man in the production of the various races of agricultural plants. There are no historical records to guide the investigator to a knowledge of the methods employed in building up these useful forms, the originals of which have, in many instances, been lost, and we can only assume that our forefathers selected those forms which showed desirable characteristics, and rejected those which were inferior. The whole weight of the evidence of horticultural practice is behind Darwin, and the experimenter would be unwise to disregard entirely the possibility of Darwin's idea being correct in certain instances. The evidence of the general existence of pure lines from controlled experiments and from practical experience only refers to a few characters in self-fertilized plants, which in consideration of their continuous inbreeding are not liable to exhibit much variation.

Slight heritable variation, which may tend to cumulation, is still to be regarded as a probability in the case of cross-fertilized species. A feature in hybrids which points to this conclusion is the cumulative effect sometimes noted in segregation, to which reference is made above. It is also probable that the commonest type of sporting is the unstable type in which segregation takes place similar to Mendelian segregation in hybrids.

Mass Selection.

Mass selection is the description commonly applied to the system of maintaining the standard of a variety by selecting individual plants, typical of the variety, *en masse* from a crop, and using the mixed seed from these individuals as a basis for an improved or uniform stock of the variety.

The system has been a regular practice on the Continent, and has been applied to all species of cereals. Its application to the improvement of the sugar content of sugar beet raised the general standard of production of that species very notably in a relatively short space of years. Mass selection is a trade practice of maintaining the purity, the uniformity, and the standard of varieties of roots. Selected roots, typical of the variety, firm, weighty, and of good shape, are taken from a crop of the variety and flowered in an isolated place to prevent chance pollination from other varieties. The seed thus obtained forms the stock seed, which is sown in the seed-producing area, and the resultant bulbs are allowed to flower and seed, this produce forming the merchant's stock for general distribution.

The system involves careful rogueing in the initial stages, and, to be successful, requires to be applied to the stock crop each year.

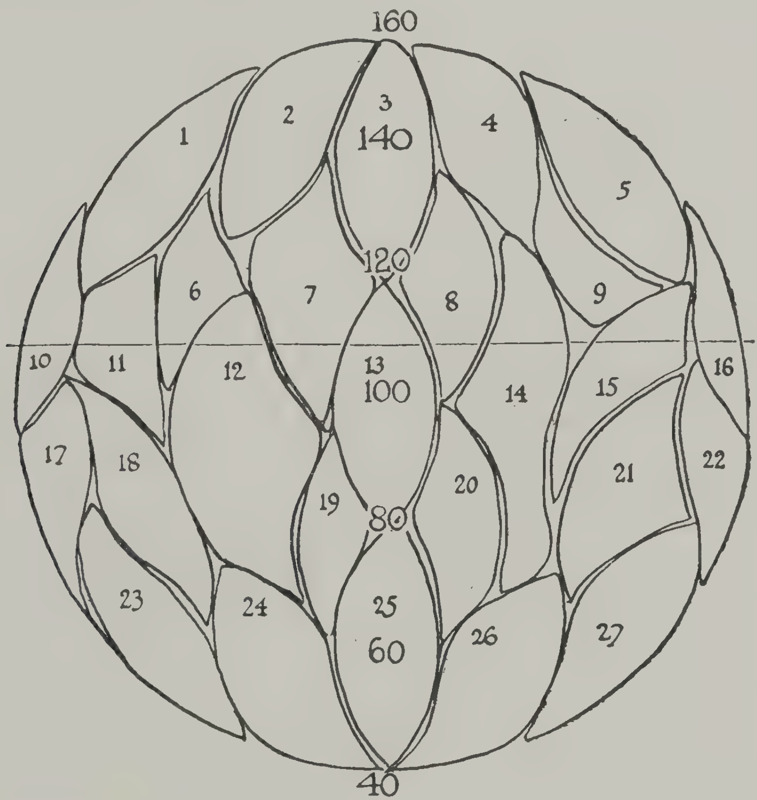
To understand the degree of improvement which can be attained by this method of selection, and to appreciate its limitations, its application to a standard cereal variety may be considered. The experience of selectors and investigators, as indicated above, has shown that a variety which has been long in cultivation consists of a number of individual types, mostly breeding true, whose average condition, under pedigree control, differs from the average condition of the variety from which they were selected, and also from the average condition of each other. It has further shown that many forms do not bear out the promise which gave them inclusion in the primary selections, and that they are indeed under the average of the parent variety. If reference is made to the diagram reproduced below, representative of the composition of such a heterogeneous variety, and if a line be drawn at, say, 110 so as to take a sector of the circle to include all forms which show a condition above that represented by the figure 110, it will be seen that such a sector, while including those forms which show the highest average condition, will also include representatives of types that are relatively weak, and whose average condition is below the average condition of the variety. Thus the best types 1, 2, 3, 4, 5 are included, and also second-rate types 6, 7, 8, 9. The remaining types included, viz. 10, 11, 12, 13, 14, 15, 16, are relatively much inferior to 1, 2, 3, 4, 5, and indeed the average of 12 and 14 is below the average of the variety.

If such a selection be used as the basis of an improved variety, it is an

advance in so far as it has eliminated many of the weakest strains, but, under continued cultivation, would degenerate in respect of average condition unless the same system of selection were continued yearly on the stock seed crop.

If pedigree selection were applied to the same variety, it would effect the isolation of 1, 2, 3, 4, and 5, as the best types, and would discard the remainder.

If a composite type were required, the types 1, 2, 3, 4, and 5 could be mixed, and the mixture would give a better type than the mixture of forms included in the mass selection.



The difference in the effect of the two methods of selection is that pedigree selection retains the best, while mass selection only eliminates the weaklings. Mass selection can thus effect a certain amount of improvement on an old variety, or it may shift the mean of one or more characters of a variety in the direction of improvement, but it fails in the want of certainty in its eliminations.

On the other hand, single pedigree selections may err in having too narrow a basis, unless when applied to the problem of raising a strain suitable for a limited territory. The average worth of a strain, taking its produce over a number of seasons in a number of districts, might not be greater than the average worth of the original variety.

In spite of the objections to mass selection as a method of giving per-

manent improvement, it is notable that many mass-selected strains have attained a high degree of popularity and a wide range of dispersal. The early Svalöf mass-selected productions are instances of success. The mass-selected Schlanstedter Rye was for half a century the standard rye of the Continent, and one of the latest varieties of oats to achieve popularity in Scotland is a full-grained, mass-selected sort from the Potato Oat, and known as Castleton Potato Oat, having been selected by Mr. Runcieman, of Castleton, Aberdeenshire.

In the improvement of the sugar beet in Germany, the principle of continuous mass selection on the basis of the specific gravity of roots was the method first practised, and resulted in improvements which soon gave a rapid increase in the sugar content. But the rate of improvement soon began to fall off, and the principle of line selection was introduced, while the basis of selection was made the absolute sugar content. Continuous selection was still found to be necessary, this being probably due to the heterogeneous character of the plants in respect of their hereditary composition.

Recent researches in sugar beet breeding seem to indicate that the improvement in sugar beet is due to the selection of mutations, and that selection according to sugar content is not reliable, variation in the sugar content being a fluctuating variation which may be of greater degree than the differences between the average condition of varieties.

The system of mass selection being that most widely practised in Central Europe at the time when the Swedish station at Svalöf was instituted, this principle was adopted there in a form which laid great stress on accuracy of measurement and of recording. By exact and systematic methods, it was hoped to put the system on a less empirical and therefore on a more productive basis, and it was thought that this system of accurate measurement would detect and render useful for purposes of improvement any small variations in a desired direction, the idea being that there were constantly occurring in a variety small, potentially cumulative variations, and that, by applying various methods of elimination, improvement in various directions could be readily obtained, and that new types could be created out of the old. The result of the application of the principle was that a great improvement on the common varieties in cultivation in Sweden was obtained, as weak strains and admixtures were thoroughly eliminated, and many of the mass-selected sorts completely displaced the varieties from which they originated. But permanent and progressive improvement did not result, and, after the preliminary success, it was found that when the level of a variety had been lifted by the application of this selective method, no further progress was to be made, and that yearly mass selection was necessary to retain the improvement effected.

The principle of mass selection was therefore discarded for the

pedigree method for producing new strains, and later work has added the principle of building up new varieties by hybridization.

Mass selection may equally with individual selection be applied to the improvement or maintenance of a standard of productiveness in the potato, and may also be applied in this crop to purification of a variety which has become mixed.

Mass selection, while it may be discarded as a method *per se* of obtaining new varieties, plays an exceedingly useful rôle in any complete general system of plant improvement.

1. It is applicable to making preliminary selections from which pure lines may be further selected. Where space and time are limited, mass selections afford a simple method of bringing together the best material in a variety and making a preliminary competitive trial.

2. It can be applied to purifying a selected strain from rogues and weaklings, and maintaining in the stock seed crop the original standard of the variety.

3. It can be similarly utilized in hybrid strains where purity of line cannot be so well assured as in pedigree selected strains.

4. It can be applied, in strains uniform in other particulars but not uniform in disease resistance, to the isolation of disease-resistant strains, e.g. in strains of turnip for finger-and-toe resistance.

The real application of the facts, available as knowledge at the present time, appears to be that before one can obtain any advantage by selection in a relatively new variety, one must leave it in general cultivation for a considerable number of years, and allow the slow occurrence of mutations or cumulative transmissible variations to take place. The method of attempting to obtain cumulative improvements by intensive selection probably fails because it attempts to go too fast, and because the selective material used is always too small in quantity. The percentage of transmissible variations occurring in a variety may be very small, and may vary in different forms according to their degree of stability: the apparent ubiquity of these variations in the variety as seen in the success of selectors in isolating them is probably relative. One might readily pick out ten such variations in a 20-acre crop of a pedigree variety after it has been grown for ten years from the date of the original selection, but the chances of the occurrence of any one of these in a pedigree plot of $\frac{1}{200}$ of an acre of the same selection in any one year is only 1 in 4000. The best source of improvement by selection is therefore the mass of the cultivated crop.

Part IV.—Hybridization as a Mode of Plant Improvement

Selective methods of plant improvement, whether on individual lines or on the mass principle, are, in the main, methods directed toward the preservation of the useful and the elimination of the unfit. They are not constructive, and if they result in discovering entirely new and useful forms which are the products of natural hybrids, as they frequently do, this is due to fortuitous circumstances.

Hybridization has a creative object, in the sense that the operation is directed towards the combining of desirable qualities in new strains, or, in terms of negation, the elimination of undesirable characteristics from strains otherwise excellent by substitution of a quality lacking. As mass selection forms a useful preliminary to line selection, so line selection is a necessary preliminary to hybridization.

In attempting to obtain a desirable end by means of a hybrid product, the investigator has a definite aim. He must therefore know thoroughly the capacity of the material which he may choose as the parental forms from which he proposes to derive the hybrid form having the desired combination. He must know the potentialities of the selected parental forms to approximate to the end in view, and must have a sound knowledge of the behaviour of each in varying circumstances. Consequently, study of these, individually in controlled plots, before crossing, is an essential of success.

The properties of a variety which make it acceptable to the grower, and valuable to the community, are, as a general rule, a high capacity for yield, good quality for the purpose for which it is required, adaptability to variation in climatic and soil conditions, giving it a useful range, and capacity to resist disease.

The general aim is therefore to produce strains which will be specialities in certain directions, but which will be general purpose forms as well. There is little doubt, however, that the production of special strains suited only to restricted areas without reference to general adaptability would extend the area of profitable arable farming.

Methods of Operation.

The operation of crossing is not generally a particularly difficult one, except in certain instances, but it entails painstaking observation and preliminary precautions.

These preliminary precautions consist in the protection of the essential organs of reproduction at the time when they are ripening for fertilization. The protection afforded must absolutely guard against the risk of self-

fertilization, and against chance fertilization from plants other than those between which the cross is to be effected.

The operation thus involves, as an initial precaution, the removal of the immature anthers from the flower which is to be the representative of the seed parent, the protection from foreign pollen of the ovary which is to be fertilized, and the protection of the flower which is to be the pollen parent from wind-borne or insect-borne pollen from other plants.

Bags of transparent paper are commonly used for the purpose of protection, and tubes of celluloid or of thin glass, stopped at each end with cotton wool, are sometimes utilized. The use of transparent paper dipped in melted paraffin wax is a time-saving expedient, as little tying is necessary: edges can be pressed together and the paraffin wax is sufficient to hold them fast. Paper tubes fixed in this way can also be very easily removed.

Time need not be wasted on precautionary measures, unless these are absolutely necessary. If the material selected for the hybridizing experiment is pure in type, the first generation will frequently indicate if a cross has been obtained, and the second generation will almost certainly do so. Success depends chiefly on the careful study of the peculiarities of the parental forms, in which the very smallest differentiating characters must be noted; on the acquisition of an intimate knowledge of the floral mechanism; and especially on the ascertaining of the relative periods of ripening of the pollen and of the stigma or receptive surface of the ovary.

Where crossing is being effected between individuals belonging to pure lines, and indeed when between individuals known to be of unstable heterogeneous hereditary composition, the parental forms should be grown alongside the progeny for the sake of easy comparison on any particular point.

In selecting forms to be utilized for the particular end in view, the selector must always have in mind the known facts of variation and Mendelian segregation, and particularly of the known apparent exceptions to the ordinary simple Mendelian law, as these may at any time direct his operations along a profitable avenue of selection or may determine what it is best to eliminate.

The Crossing Operation in Normally Self-fertilized Species, e.g. Cereals.

Except in the case of hybridization of rye, precautions against extraneous fertilization are unnecessary, from the practical standpoint, in the case of British cereals. The operation of crossing is so easily performed that it is simpler to multiply it and to reject, in the first or second generations of the product, any plants of doubtful origin than to spend time in taking elaborate precautions.

The operation of crossing barley is a very simple one, and its description in detail will illustrate general methods as applied to the crossing of cereals. The necessary implements are a pair of dissecting scissors, a pair of needle-pointed forceps, and a small bottle of methylated spirit.

The plants between which the crossing is to be performed are first selected and labelled, each label carrying the reference number selected for the cross. Thus one label should carry the information " Pollen parent of No. . . . ", and the other " Seed parent of No. . . . ".

Selection of Pollen.

The flowers in the centre of the ear are the first to ripen. Ripe pollen is readily obtained in quantity in sunny weather. An ear, well free of the sheath, and in which the centre flowers of the ear are just ready to ripen their pollen, is selected. The ear is cut off and inserted in the pith of a bamboo cane, which is set up close beside the plant which is to be the seed parent. The glumes enclosing the flowers are cut across by means of scissors just above the top of the anthers, the position of which can be readily seen through the slightly transparent glumes. The tops of the glumes along with the awn are thus removed, and this allows more rapid ripening of the anthers, which, if the weather is dry and sunny, will protrude in rapid succession practically as required.

Attention is then immediately directed to the seed parent which has already been selected, the selection being determined by the degree of emergence of the ear from the sheathing leaf. This varies with the variety. The correct stage for the operation on Chevalier or Goldthorpe types is when the ear has emerged from one-half to two-thirds. At this stage the centre flowers of the ear are just beginning to ripen. For operations on Archer types it is necessary to select the heads at an earlier stage, as the floral development of this variety is completed while the ear is yet within the sheath.

The awns are rapidly trimmed off from all the glumes of the ear just at the point where they merge into the outer glume.

The forceps is closed and inserted at the top between the glumes enclosing the flower. Then the spring is released and the points of the forceps, springing apart, force the glumes open, exposing the stamens to view. With a little practice, the operator soon becomes expert at removing the stamens by closing the forceps gently on all three at once and withdrawing them by a simple quick action. Mutilation of the glumes in the process does not prevent seed formation. If any one stamen is broken, or if the stamens are too ripe, the whole flower is cut off, as pollen may have escaped from the broken or ripe anther on to the feathery stigma.

The operator then dips the forceps into the spirit bottle to destroy any pollen which may adhere, and dries the instrument by waving it in

the air. He then takes an emergent anther from the prepared ear by his side, and inserts it between the glumes on the ear of the seed parent from which the three stamens have been removed. The glumes are then gently closed. A whole ear can be pollinated in about fifteen minutes, and a skilled operator is assured of 80 to 90 per cent of successful hybrid grains. The upper and the lower glumes are not pollinated; the operation of removing the anthers commences from the middle of the ear, and proceeds upwards and downwards. The condition of ripeness of the flowers gives an indication of the possibility of getting a successful cross; the upper and lower flowers which are too immature are entirely removed. Each head operated on is carefully labelled with the number selected for purposes of identification together with details of the date and hour, a record of the operation at the same time being made.

The cutting off of the top of the glume leaves a sufficient indication of the flowers on which the crossing operation has been performed. Covering of crossed flowers is unnecessary, unless to protect them from birds if the plants are in the open. At experimental stations where hybridizing work of this nature is carried on, selected cultures are grown in a wire cage, and the whole material is protected in this way from birds and rodents throughout the season.

Where protection has to be given, a bag of transparent paper is used. Holes must be made in the upper end to allow of respiration and transpiration. The bag must be closely applied to the stem to prevent invasion by earwigs. If protective coverings are used it is necessary to give the plants support, as the large surface exposed to the wind by the covering bag induces stem breakage.

The technique of crossing wheat is similar to that applied to the crossing of barley. In this plant, however, there are two spikelets—each with more than one flower—at each node, and, as the flowers on the same spikelet do not ripen simultaneously, it is necessary to remove the immature flowers from the top of each spikelet, leaving only the lower flower on each spikelet to be utilized for the crossing operation.

The hybridization of oats is a much more difficult matter. The spikelets here consist of from one to three flowering glumes, the lower and larger of which opens first. The opening of the main flowers on the spikelets of the oat plant follows the order of their emergence from the sheathing leaf.

The oat flower, while large and easily opened, is susceptible to the mutilation involved in forcing the glumes apart, but the tips of the glumes may be cut off without fear of injury. It is difficult to judge the precise stage at which pollination is effective. The exact moment is just before the normal opening of the flower. The order in which the flowering glumes have emerged from the sheath can be readily determined by passing the ear through the closed hand. When the anthers of one of the flowers

are just emerging, the flower next below in the succession of emergence from the sheathing leaf is in order for the crossing operation.

As the anthers are just on the point of bursting, rapid and skilful handling is necessary to snatch them out in one operation, without letting pollen escape from them during their removal. The foreign pollen introduced must be in a fine, floury condition, and warm, dry weather is necessary for obtaining a successful cross. The ear takes a considerable time to flower. Skilful, assiduous, careful work is necessary to ensure a quantity of hybridized seeds, and the operator must be prepared for a considerable percentage of failures. Consequently, although only a single example of the desired cross is wanted, much time must be spent and care taken in ensuring its production.

The seeds of cereals which are procured as a result of the crossing operation are frequently misshapen and shrivelled, but they must not be discarded on this account. Indeed, well-formed seeds should always be specially noted as probably having resulted from a non-effective operation.

Hybridization of Potatoes.

New varieties of potatoes are obtained by raising plants either from self-fertilized seed derived from the potato "berry" or from cross-fertilized seed of the same derivation.

Some varieties bear plums readily, others can scarcely be induced to bear fruit at all. Many varieties do not readily flower, the flower buds drooping before they open. Although the potato plant is believed, from the construction of its flower, and from the fact that the flowers are not visited by insects, to be almost always self-fertilized, there are probably no pure lines to be found among the cultivated varieties at all, many of these varieties being the first generation of crosses between unstable varieties of mixed ancestry. Hence a large number of distinct varieties may be procured by sowing the seeds of a single plum.

The chance of obtaining desirable forms or definite desirable combinations is uncertain for the following reasons.

1. Many varieties are difficult to bring to fruit, and artificial means have to be resorted to in order to induce the formation of plums. Fruiting takes place most readily in slight shade. Protection from wind is necessary because the pendant fruits are readily broken off before they ripen.

Artificial methods of inducing the formation of fruit consist in the prevention of tuber formation, or in the mutilation of the base of the stem bearing the flowers.

It is sometimes necessary to rear the plants under glass in order to get a particular combination.

The application of phosphatic manures favours flower production and development.

2. Many varieties are barren of pollen or their pollen is ineffective in fertilization. The production of pollen can also be induced by prevention of tuber formation and by stem mutilation.

3. Varieties being heterogeneous in respect of their hereditary composition, the sum total of useful characteristics of one variety cannot be combined with the useful characteristics of another with any degree of certainty. It is not at all certain, even if a combination of two characteristics only were sought, that such a combination would emerge from the results of a crossing operation without other undesirable characteristics being superadded.

4. The true character of a seedling is not shown in the first years of its cultivation. Seedlings which at first show promise frequently degenerate rapidly, while coarse uninviting forms may in time be the most useful. The area required for testing and the time necessary for comparing the hundreds of forms which are produced are both very considerable.

The operation of crossing one variety of potato with another is a simple one, provided effective pollen can be procured.

If the variety on which it is desired to procure a berry normally has sterile pollen it is not necessary to remove the stamens, though it is advisable to do so. The mutilation caused by the removal of stamens at an immature stage does not hinder fruit formation if the stalks (filaments) of the anthers are not also removed.

The best method of transferring pollen to the stigma of the flower on which the crossing is to be made is to split the anther along its normal line of opening with the point of a sharp forceps, and transfer the pollen which collects on the forceps point during this operation direct to the stigma. In order to make the crossing operation effective the same stigma should be pollinated on several successive days. If an effective pollen parent is utilized, and the operation is thus repeated, berries can be raised on any variety which flowers.

Analysis and Application of the Results of Hybridization.

The aim of the investigator who seeks improvement of products by means of hybridization is to secure a combination of qualities of such a kind as does not exist in any variety of the cultivated species of which he desires to obtain an improved form.

His object is more than the selector's aim—discovery: it is creation of new types.

While the great mass of highly specialized varieties which have been bequeathed to the modern world by our ancestors, have been the result largely of haphazard selection, promiscuous breeding, and empirical choice, enlightenment on the facts of variation and heredity will greatly assist in the solution of the problem of further improvement.

There is little doubt that the personal factor is of great account, and that many improvers have a genius on which depends their success; yet one would suppose that scientific knowledge added to genius would ensure success in double measure.

It has to be remembered, however, that the results of statistical analyses of variation and heredity, as applied to the solution of practical problems, have been very meagre, and while there is no reason to doubt the accuracy of the results, it is permissible to doubt their applicability as general working principles.

It is important to keep an open mind: if an investigator does otherwise he may find a dead end. This was the preliminary result of following a fixed idea at the Swedish station at Svalöf. The pure-line idea has still to be thoroughly tested on a big scale over a long series of years, for, although Vilmorin has demonstrated that cultures of varieties of wheat remain the identical of their originals after fifty years, criticism has not failed to suggest that this is due to selections true to type being made yearly for the cultures. The experiences of selectors produce evidence which is diametrically opposed. They sift out an old variety and isolate a large number of strains that are diverse in character, yet in general type approximating to the recognized type of the variety, and find that practically all these breed true, and that further selection within pure lines is of no effect as regards improvement. The inference is either that change takes place in a variety through admixture by cross-fertilization with other varieties, or that the changes are so slight as to be inappreciable in small pedigree cultures grown for a short space of years.

The mutation theory attempts to explain the occurrence of these variations, but there are no notable records of mutations occurring in pedigree cultures of cereals. The application of Mendel's law to the problem of recognizing essential improvements in hybrid forms is very limited. In principle the law is essentially statistical, and, being so, can only be applied to characters which are capable of being measured. But most of the desirable qualities of cultivated plants are substantive, and depend on a physiological condition frequently impossible even of rough estimation. Correlations between physiological characters and morphological features probably exist: it has been shown in investigation on insects by American investigators that Mendelian characters are in some cases linked in groups. But correlations may not always be hereditary features. For example, early ripening in oats is correlated with poor yield. But early sowing of high-yielding late varieties, by inducing early ripening, lowers the yield of the crop. Hence the hope of getting a knowledge of correlations by Mendelian analyses is somewhat illusory. Nevertheless the investigator should have a knowledge of all the known facts of variation and heredity without placing implicit confidence in any one or all of them to guide him aright.

The general applications of Mendel's law are:

1. The form produced in the first generation of an attempted hybrid between two fixed strains will generally indicate in some manner that hybridization has been effected. Even in close crosses of similar type there should be a difference from the parental forms in the degree of vigour, which is most frequently but not always positive.

2. The increase in vigour, which is a common characteristic of the F_1 generation, and which is considerably reduced in the second and following generations, points to the probability of the maximum results of hybridization being obtained always, in the case of crops propagated vegetatively, from the first generation of the hybrid.

3. In the F_2 and succeeding generations the process of segregation may result in one or more cases of the occurrence of stable examples of the combination of characters expected, and for which the crossing was effected.

4. A guide is afforded to the principles on which analysis of results should be made, and the various phenomena which have been noted as occurring in hybrids may at any time indicate a fertile line of investigation.

Utilization of Hybrids.

The utilization of the immediate results of hybridization is limited to perennials in which the act of fertilization stimulates the fruit—which is the immediate economic product of the union—to greater productivity according to the nature of the varieties concerned in the union.

Many varieties of apples, for example, are self-sterile, and the production of fruit depends on pollination by another variety. The degree of productivity in the case of some varieties depends on the selection of varieties which are grown along with them. Much research has been carried out in Australia and in America with a view to determining the best combinations of varieties in a mixed orchard.

The utilization of the products of the first generation has in the past been largely confined to plants propagated by vegetative means. The F_1 generation of a hybrid is frequently notable for increased vigour and productiveness as compared with either of the parent forms. In the case of a perennial species propagated by vegetative methods the maximum improvement by hybridizing would therefore be expected in a first generation strain. Relative to the potato this is generally accepted as a working principle. Controlled experiments on the products of self-fertilization of potato varieties have demonstrated that derivative varieties obtained from the seeds of self-fertilized plants are generally inferior to the parent variety, and are liable to rapid degeneration. In view of the heterogeneous character of varieties one would suppose that many

useful combinations would accrue from self-fertilization, as quite new combinations are certain to arise. When Mendelian values for characteristics of the potato are thoroughly worked out, advance may lie, in respect of certain features, in the hybrid combination of selected F_2 derivatives of two varieties rather than in the combination of the varieties themselves.

But hybridists have been greatly struck with the frequently shown excellence of the mixed product of the F_1 and immediately succeeding generations.

American investigators have shown the possibility of utilizing this in the case of maize. The increased vigour and productiveness of hybrids is particularly notable in the case of species which are always cross-fertilized. The floral arrangement in maize is such as to ensure a large amount of cross-fertilization, for the pollen is carried on a tassel of flowers, which produce stamens only, and which surmount the cob, which is composed of flowers carrying ovaries and no stamens.

Continuous self-fertilization in homogeneous strains of maize leads to degeneration, which is rapid at first but in a few generations reaches a maximum.

Hybridization can be effected by growing two varieties in close proximity and detasselating all the plants of the one which is to be used for the production of the hybrid seed. Preliminary experiment would readily indicate suitable varieties for the purpose. Wind being an effective agent in the pollination of maize, the planting of alternate rows would secure the desired result, and sufficient hybrid seed to sow any ordinary field could be obtained with very little trouble.

The possibility of utilizing products of the first generation of tomato crosses has also been shown at the New York State Experiment Station. Certain varieties of tomato, when hybridized, yield seed which produces in the first generation plants which bear fruit in much greater abundance than either of the parents. The tomato produces seed in abundance, and a relatively small number of crosses is capable of yielding a considerable quantity of seed. It should thus be a simple matter, after determining a suitable high-yielding hybrid, to fill a tomato house with F_1 hybrid plants.

It is possible that the use of mass hybridization as applied in maize might be a practical and useful principle if applied to other species which are normally cross-fertilized. Few species can, however, be depollinated as maize is, and if natural pollination was depended on to secure the result, a certain percentage of the seed would be seed fertilized from a plant of the same variety. Uniformity of product would therefore not be anticipated. Yet the possibility of its application in the case of mangel and beet, the flowers of which are normally cross-pollinated, should not be overlooked.

In the case of annual species normally self-fertilized there is no chance of utilizing the F_1 generation at all as a crop product, as hybrids must be the result of an artificial pollinating operation.

But the F_2 and succeeding generations retain in gradually decreasing amount the vigour and characteristic robustness of the F_1 generation. It has already been shown that, in respect of any single pair of Mendelian characters, the derivatives of a hybrid form in a comparatively few generations become stable, this stability being expressed as a mixture of forms similar to the parents. With the stabilizing process they lose the robustness associated with the heterogeneous products. But the relics of vigour still left in earlier generations might well be utilized. In the case of wheat and barley, a multiplicity of crossing operations can be readily performed between the same two strains, and, provided the original forms are within the bounds of uniformity of an ordinary commercial variety, a sufficiency of seed might be obtained in the second generation to produce a commercial crop in the third or fourth generation. This is based on the assumption of increase in vigour always occurring in a hybrid even when the parental forms are closely allied: in self-fertilizing species this is generally the case.

The utilization of hybrids which have been produced for the purpose of procuring a definite combination of characters, frequently involves very careful and patient analysis of the produce in the second generation and often in the generations succeeding. If the characters of which a combination is desired are capable of being determined in their segregation, the desired result may be obtained in the second or third generation. In order to make analysis as certain as possible in the early stages, crosses should always be made reciprocally. The parental forms should be stable and should be as close in general characters as possible.

But in many cases where a combination of desirable characters is required, it is necessary to cross widely differing varieties, and to trust to empirical selection.

The trouble in arriving at useful results arises from the fact that it is necessary to discard a large quantity of the selective material in the second generation.

The method of dealing with the products of artificial hybridization differs from that applied in the case of pedigree breeding only in so far as, while the number of pedigree selections is constantly decreasing, the number of different types derived from a crossing is constantly increasing. In each of the plants produced in an F_2 generation there may be essential differences from all the others. The produce of each selected plant must therefore be grown separately. But a similar state of affairs occurs in the third generation, and if elimination has not already been done in the preceding generation, it must be done at this stage on a big scale, for the

application of comparative tests to the great multiplicity of types obtained would be impossible.

If crosses made for a specific purpose are taken between two widely differing forms, the possibility of the occurrence of many differing combinations is so great that the desirable combination may not appear in a useful form either in the second or third generation. In such a case, probably the best method to use would be to sow out the whole of the produce of each generation in mass for four or five years in such a way that it could be all readily examined, and to postpone selection until most of the derivative forms are relatively stable.

The increase in the degree of a characteristic, which occurs frequently as a result of hybridization, is an occurrence which may be on occasion utilized for obtaining valuable strains; though this cannot be taken as a reliable method of attaining an objective, the experiments should always be ready for such an occurrence incidentally.

During the propagation of new varieties which are the result of crossing, every care must be taken to ensure that they are "fixed" in essential features. It is probable that absolute uniformity cannot be attained in a derivative from a hybrid except by individual selection after it has been in cultivation for some time. There are of necessity in a hybrid many characters of mixed origin, the segregation of which is not capable of being noted, and it is unlikely that the physiological qualities of the seed in all hybrids is uniform. But uniformity in strength of straw, in height of plant, in general appearance and morphological features, in evenness of ripening, and in yield should be ensured before it is finally put on the market as a commercial variety. This test of uniformity, to be exact in its results, involves the sowing of the variety in separate lines for at least two years after selection, each line being the product of a single plant.

Multiple crossing is a system of hybridization which has been successfully applied both by Garton and by Farrer to the formation of new varieties. The system aims at the combination of a large number of useful characteristics in one form. It involves duplicate, triplicate, or quadruplicate crossing of superior forms extracted from diverse hybrids. The system appears to have great possibilities, for, even although analysis of the results might be impossible, empirical selection might yield useful results.

The application of natural selection as a method of securing the fruits of hybridizing work is a line of action which may be applicable when certain specific characters are required in the products.

The application of this principle has been put into operation at Svalöf to determine winter hardiness in new hybrid wheats. The principle might conceivably be applied in other directions, particularly in breeding for resistance to certain diseases, which vary in virulence with climatic conditions in different years.

Hybridization as a Method of Securing Resistance to Disease.

The breeding for disease resistance is generally in all cases only possible by a modified form of this method of selection being applied to the selective process, as breeding for immunity from a specified disease involves the exposure of the products to the effects of the disease. The application of the pedigree method of selection to producing varieties resistant to or immune from disease has already been considered. The improvement which may be effected in this direction can be heightened by the application of hybridizing methods.

Disease may be considered as any specific agency which interferes with the normal development of varieties of plants belonging to a definite group, and brings about a pathological condition in the individual plant. The term disease may therefore be regarded as including the effects of attacks of specific insect and animal pests, fungoid diseases, constitutional weaknesses, and weaknesses in development and in growth due to unfavourable environmental conditions.

Great specialization accompanies a small range of adaptability. It is natural to assume that the more artificial a living product becomes, the less will it be able to withstand adverse environmental conditions.

The incidence and spread of sudden blights on various species of plants is probably due to the refinement of a species giving scope for the adaptation of a disease in environmental conditions where it could never have thriven on the wilder forms. Examples of disease resistance are stated above.

Resistance to disease is therefore a capacity to thrive when exposed to pathological conditions in which other plants of the same kind will not attain their full development or will die. It is thus a physiological characteristic and as such should be capable of transmission.

In general the more specialized varieties are the least resistant to disease, and it would appear that it is practically impossible to obtain in a single form the highest degree of productiveness and quality along with the highest degree of resistance. The aim of the hybridist, while keeping the greatest excellence combined with the highest resistant quality as his ideal, is generally to accommodate these qualities in the best combination that the balance of nature will afford.

A considerable degree of success has been attained by hybridists in obtaining varieties of wheat which are rust resistant.

The problem of raising rust-free strains by hybridization is one which, owing to the importance of the problem, has attracted the attention of all cereal hybridists, partly from the fact of the great loss occasioned by the disease, and partly by the fact that a great diversity was obvious in the resistant qualities of different strains.

It fell to Professor Biffen to show that rust-resistance was a physio-

logical quality which followed the rule of segregation according to Mendel's law. The experiences at Svalöf do not accord with Biffen's results, and it would appear that the real facts of the case are that the nature of the degree of segregation depends on the varieties employed in the crossing, and that, even so, the degree of rust resistance of any variety varies with the climatic conditions under which it is grown. Further there are known to be specialized forms or "biological varieties" of several of the rusts, and the possibility of their carrying their specialization to non-susceptible varieties in certain conditions is not to be discounted.

Hybridization in Relation to Diseases of the Potato.

The potato plant offers one of the best subjects for the study of the heritable qualities of certain diseases, notably *Phytophthora infestans* (blight) and wart disease.

Following on the catastrophe caused by the effect of the blight in 1845–6, the area under cultivation for potato crop was greatly reduced for a time. The main ideal of the raiser of new varieties was thereafter to produce types little liable to the effects of the disease. Many varieties excellent in every respect were put into commerce, and some were markedly resistant. The more resistant varieties were generally the poorer yielders, and the problem before those engaged in the production of new varieties has been to find varieties which show an equable balance between cropping power, quality, and resistance to disease.

The problem has, on account of the spread of that insidious and persistent disease, wart disease of potato, been opened up anew and extended. One of the primary considerations for the raiser is now to produce varieties which will be immune from this disease. This makes the problem of determining what to keep and what to throw away somewhat easier in one respect, as, immunity from this disease being an absolute quality in many known varieties, absolute immunity provides a rigorous criterion which, when applied, determines eliminations at once, for no new variety has any chance of success unless it is immune from this disease. On the other hand, the problem is made more difficult in view of the lack of knowledge of the factors which govern the condition of immunity and its transference from one generation to another.

The method of hybridization has been the method employed by producers of new varieties for obtaining resistance to disease; the principle of selection employed was generally that of breeding together blight-resistant varieties, or, more commonly, breeding prolific varieties with highly resistant types and selecting from the results of the first generation of the cross. There is, however, no recorded information of the nature of the heredity of blight resistance, and the selection of varieties has probably always been on the principle of trial and error.

The same applies to the production of varieties immune from wart

disease. The fact of the chance circumstance that Sutton's Abundance and Langworthy and Champion are immune from this disease probably saved the country from an early and more rapid spread of the disease. The only practicable method at present of getting rapid results in the development of immune varieties is to breed indiscriminately, and subject as large a number of seedlings as possible to the immunity test. The possible combinations obtainable from varieties appear to be legionary, and the prospects of obtaining pure breeding forms illusory. A great number of varieties are probably combinations derived from the cumulative crossing of first-generation hybrids: the lack of development of the reproductive organs suggest that in many there may be a trace of the species hybrid as well. But if forms resistant to blight, immune from wart disease, and breeding true to these qualities from seed derived from the fruit, could be produced, we might be within measurable distance of an easy solution of the problem of obtaining first-class varieties —from the point of view of yield and quality—which would have the disease-resistant characteristics superadded.

General Considerations.

The ultimate economic effect of the introduction of new and improved varieties of plants depends, on the one hand, on the excellence of the productions, and, on the other, on the wideness of their distribution in areas to which they are specially adapted.

Plant improvement in the past has been largely due to the sporadic efforts of individuals whose activities were without correlation or continuity. The later phases of this method of advance have, in Britain, been somewhat organized by the continuation of efforts in the direction of improvement by soundly established firms, which have put production of novelties on a commercial basis. But this organization of effort leaves much to be desired, so far as it relates to heritage of knowledge for the public benefit, as it lacks co-ordination between individual workers. Individuals, or the firms they represent, are naturally jealous of the specific information which is based on personal discovery, and which they apply to the creation of their own specialities. There is little doubt that the success of many individual plant improvers is founded on particular knowledge of a few special plant forms, added to a faculty for using these aright. These particular forms and particular items of knowledge are lost to the world with their discoverer, and the new generation of breeders has to start afresh.

The establishment of scientifically conducted stations, the activities of which are directed as much to the collection and dissemination of knowledge as to the distribution of their productions, has already become a feature in all progressive, civilized communities, and there is little doubt that the newer generations of plant breeders will be attracted to these

establishments, and will look on their individual work as in the common cause rather than in their own private interests. The rapidity of progress, which is possible of attainment by the pooling of information in the common interest, has been abundantly shown in the methods adopted by Germany in relation to her scientific industries.

The systematizing of investigation saves an enormous amount of time and labour uselessly spent by individual investigators: already the operations of these public stations have indicated a great number of these blind alleys into which the amateur investigator is apt to be tempted.

But, besides the systematizing of investigation and the co-ordination of knowledge and effort, there is another important function of centralized stations. It is the organization of the distribution of productions, and the maintaining them at the standard of excellence which they represent at the time of their first distribution.

In order to utilize to the best public economic advantage the fruits of their work, plant-breeding institutions must undertake the testing of their productions in various localities where are represented differing types of soil or other conditions, must maintain adequate stocks of pure seed to supply the yearly demands of the seed farmers, and must undertake the inspection and registration of crops and stocks of the seed farmers, in order to ensure that the ultimate distribution to general cultivation will represent a uniform product.

The Swedish station at Svalöf is probably the best example in existence of organized method in dealing with a complete system of improvement, from production to distribution. The main scientific institution deals with the discovery and testing of new varieties; an associated commercial company deals with the registration of crops and their distribution.

A public institution should go further. The operations of the Swedish station leave out of account the work of private individuals. The ideal scheme of organization of improvement must take into account all efforts in the direction of advance, and should be prepared to test and register crops of individual private producers.

Small Spelt: Einkorn (*Triticum monococcum*, L.)

Emmer or Two-grained Spelt (*Triticum dicoccum*, Schr.)

Common Spelt Wheats: Dinkel (*Triticum spelta*, L.)

Hard or Macaroni Wheat (*Triticum durum*, Desf.)

VARIETIES OF WHEAT

[*Vol. I, facing p. 58*

WHEAT

By W. G. SMITH, B.Sc., Ph.D.

The use of wheat as a food for man dates back to the earliest records of history. Grains of more than one kind of wheat have been found in the remains of dwellings of early man, and in the later, but still very ancient, remains of Egypt, Babylonia, and other old centres of civilization.

Wheat was exported from centres such as these, and, when the early races colonized new lands, they sowed wheat and cultivated it where climate permitted. The cultivation of wheat has thus spread over the whole earth, and it is an important foodstuff even in competition with rice in the East, maize in America, and millet in Africa.

The crop, however, has its limitations, mainly as regards temperature and rainfall. Towards the Poles, in Canada and Northern Europe, during the growing season there must be a temperature sufficient to mature the crop. The severe winter conditions of North-West Canada necessitate the use of varieties that are sown in spring and ripen early.

In the higher parts of Britain and in mountainous countries, wheat ceases to be a regular crop where late springs retard growth, and the crop does not ripen with certainty every autumn.

The rainfall requirements are seen towards the Equator and adjacent to deserts, as in Australia, Africa, and the Western United States. It has been estimated that wheat requires at least 10 inches of rainfall, but this low amount is sufficient only where the climate is cool and the soils fertile.

The chief wheat-growing countries vary considerably in climate and soil; and to meet the varied conditions, man has expended great energy in finding suitable varieties. The wheat plant, however, has a great capacity for variation, and innumerable races are now in cultivation.

Wheat belongs to the genus *Triticum*, of the natural order Gramineæ or grain-bearers. The characters of the genus are found in the ear. If an ear of ordinary wheat is stripped, there remains a central axis with one series of notches on one side, and another series on the other side, alternating with the first, not opposite. Each notch is occupied by a spikelet, attached directly by its base, with no stalk; barley has three spikelets in each notch. The spikelets are attached so that one of the

broad sides is towards the axis, not edgewise as in ryegrass (*Lolium*). This broadwise spikelet is found in wheat (*Triticum*), the couch grass (*Agropyrum*), and rye (*Secale*).

The structure of a wheat spikelet is seen by removing the parts and laying them out in order as removed. The outermost chaffs (barren glumes) on each side enclose the spikelet. In common wheat these have a broad blunt apex and no awn; rye has very small barren glumes. The rest of the spikelet is occupied by two to five or more florets, each represented in the ripe ear by a grain enclosed in a thick chaff (flowering glume) and a thin chaff (the pale). The larger grains lie nearest the outer edge of the spikelet; the younger florets are in the middle, but as a rule they fail to mature a grain, and are represented by the two chaffs.

The variations in ear characters are numerous, and these form the basis of classification. Uncertainty as to parent forms has led to great divergence of opinion, so that hardly any two authorities adopt the same system.[1] This, however, is not important from the grower's point of view, because the wheats cultivated on a large scale are almost all varieties of common wheat. Types varying from this are not often seen in field cultivation. Common wheat and some other types are distinguished by the axis of the ear remaining whole on threshing, while the mature grains separate easily from the chaff. Spelt wheats have an axis that breaks up, so that a sample of a Spelt variety consists of separate spikelets still entire with the grain enclosed in the chaffs.

One-grained or small Spelt has one small mature grain in each spikelet; the ears are small and awned and the whole plant is more like a small barley or grass than a wheat. It is cultivated in some poor soils in Southern Europe.

Two-grained Spelt or Emmer matures two grains in each spikelet; the ears are flattened and awned, rather like a two-rowed barley. Its cultivation dates back to prehistoric times, but is now limited to districts in countries like India and Abyssinia, and in Europe occasionally as a spring wheat.

Common Spelt has two or three large grains in each spikelet. Some varieties are awned, others awnless; while the chaff may be white, red, or blackish. It is cultivated to some extent in Europe and America.

Polish wheat is grouped along with the wheats with a tough axis, but in other respects it has a distinct appearance. The ears are long, open, and awned, with the outer (barren) glumes about an inch long; the grain is larger than ordinary wheat and is hard and flinty. It is cultivated only in some warm countries like Spain and Italy.

There still remains a large number of varieties which at first sight

[1] The classification and descriptions of the known varieties of wheat are included in Professor John Percival's comprehensive monograph: *The Wheat Plant* (463 pp. and 228 illustrations), London, Duckworth & Co., 1921.

Rivet or Cone Wheats (*Triticum turgidum*, L.)

Dwarf or Club Wheats (*Triticum compactum*, Host.)

VARIETIES OF WHEAT

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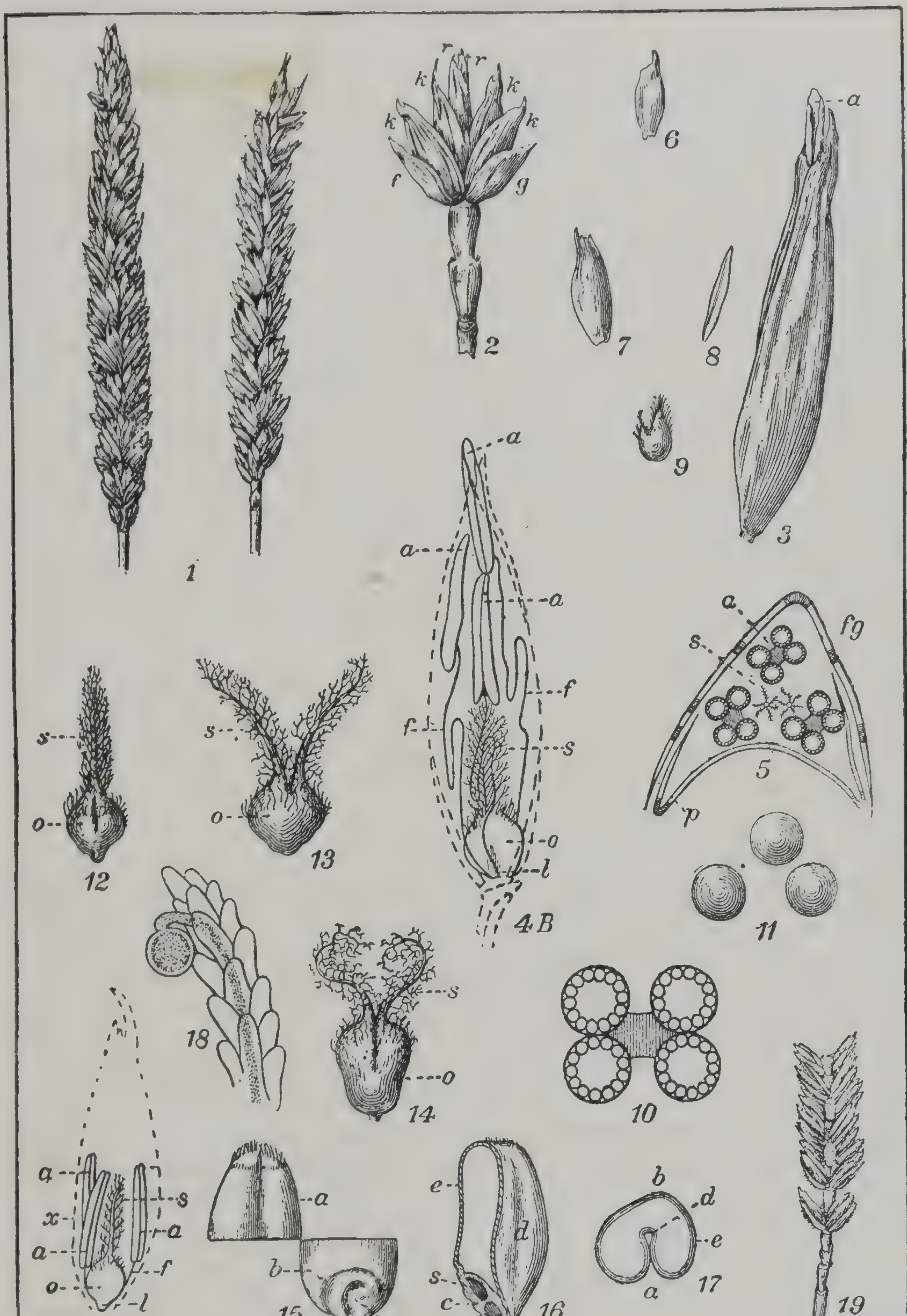

Fig. 1

1, Ears of wheat; Blue Stem (right), Fife (left). 2, Spikelet with part of axis showing notches: *f*, *g*, barren glumes; *k*, florets with grains; *r*, florets with no grains. 3, Single floret (× 5). 4A and 4B, Stages of flowering: *a*, anthers; *o*, ovary with feathery stigma. 5, Plan of flower cut across: *fg*, flowering glume; *p*, palea. 6, Barren glume. 7, Flowering glume, awn short. 8, Palea. 9, Lodicule. 10, Anther, cross section (× 30). 11, Pollen grains. 12, Ovary and stigma before flowering. 13, At time of flowering. 14, After flowering. 15, 16, 17, Mature grain: *c*, the germ. 18, Part of stigma, with germinating pollen grain. 19, Ear prepared for crossing. (By permission of United States Department of Agriculture, from *Bulletin 29*, 1901, p. 51.)

do not seem to differ widely, and may be kept together as common wheats. Most authorities recognize four important groups, viz. (*a*) Macaroni, Hard, or Durum wheats, with awned ears and large, hard, flinty grains; (*b*) Rivet, English, or Cone wheats, with square ears, generally awned, and with velvet chaff; (*c*) Dwarf, Club, or Hedgehog wheats, with short square ears, and short stiff straw; (*d*) Bread wheat. These are linked by intermediate forms, and a number of the newer varieties of commercial wheat have been obtained by intercrossing the races.

The earliest cultivation of wheat recorded was in the countries of Europe, Asia, and Africa adjoining the Black Sea and the Mediterranean, and it is in these countries that uncommon wheats may still be seen in cultivation. The ancient wheats include Spelts and those with a tough axis, and most of them are quick-growing varieties.

The greatest moisture in Mediterranean countries falls in autumn and winter, being followed by a hot dry summer; hence the wheat crop is sown either in autumn to be harvested about May, or early in spring with a later harvest. The older wheat varieties grown there were almost all awned, and with small ears.

When wheat cultivation extended to Central and Western Europe, the Spelt races seem to have gone out of favour, and preference was given to races with a tough axis and naked grain. Hardiness is essential in the western countries, and this is a feature of common wheat, including the Rivet and Dwarf wheats.

The commoner wheats of East Lothian, as described at the end of the eighteenth century, included tall, long-eared wheat from seed from Hereford, short-eared wheats from Essex seed, Small Wheat, a dwarf variety, Early Lammas Red, and Velvet-chaffed.

Authors about 1870 make no mention of these varieties but name the following: Talavera, Hunter's White, Chidham, and other long lax-eared, awnless wheats with white grains; Fenton, Victoria, Trump, white-grained with denser ears; Hopetoun, Lammas, &c., red-chaffed, awnless with red or white grain; Rough Chaff White, Velvet-eared, Old Hoary, &c., with velvet chaff; Thickset, and other short-eared wheats. One author in 1875 refers to a new sort called Squarehead recently introduced.

These records show that autumn-sown awnless wheats were the rule, whereas awned varieties were chiefly used for spring sowing. There was still a distinct preference for long lax-eared races, and white wheats were more grown than red. Rivet and other velvet-chaffed varieties were mainly limited to the heavier soils in the drier districts. Dwarf creeping wheats were used locally.

The first half of the nineteenth century saw the selection of improved races carried on by men like Le Couteur, in Jersey (Talavera wheat); Marshall, in Yorkshire; Patrick Shirreff, in East Lothian (Hopetoun, Pringles, Bearded Red, Bearded White, &c.); and by Vilmorin, in France.

Common Wheat (*Triticum vulgare*, Vill.)
Dense and lax-eared forms

Polish Wheat (*Triticum Polonicum*, L.)

VARIETIES OF WHEAT

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During the same period, hybridization, though not unknown earlier, began to be more utilized, and Shirreff, Maund, and Raynbird exhibited hybrid wheats in London in 1851.

The improvement of wheat is now vigorously carried on in all wheat-growing countries, partly by private enterprise, partly by the State. Selection of pure lines and the hybridizing of these have furnished most of the newer races, and the type of wheat now grown differs from that of fifty years ago. Autumn-sown wheats still prevail in all temperate countries with a winter not too severe, but there has been a great increase in the acreage of spring-sown wheats in such countries as the Canadian North-West, and the Western Prairie states of the United States of America. India, Australia, and other warm dry countries have special requirements for early maturing wheats. Another change is the general adoption of close dense-eared varieties of the Squarehead type, with red or white grain.

In Britain the demand is for a high yield of grain and useful straw that is not too liable to be laid in a wet autumn. These requisites, on the whole, seem to be given better by Squarehead races than any other. The Squarehead and Stand Up type of ear has probably a multiple origin. Some strains are selections of hybrids of compact-eared common wheats, others are derived from Club wheats, and in recent years, new races have been obtained by crossing common wheat with Spelt and Rivet wheats.

The crops of recent years have been chiefly Squarehead's Master, Red and White Stand Up, Standard Red, Browick, Victor, &c. Varieties from other countries have also been tested, mostly squareheaded, including French (Dreadnought, Marvel); Swedish from Svalöf (Squarehead, Grenadier, Sun, Iron); Dutch (Wilhelmina); and Danish (Tystofte White, Danish Squarehead).

Resistance of wheat to rust or mildew may also be secured by plant breeding; and in various countries where losses are serious, efforts are in progress to obtain the combination of quality, yield, and resistance to rust. Little Joss (Squarehead's Master × Ghirka) is a Cambridge hybrid of this kind.

The milling and baking qualities and strength of wheat have received much attention in recent years. Britain has long imported baking wheats from Hungary and Russia. More recently, the hard wheats of Canada and the United States of America have found a ready market because of their superior baking qualities.

The produce of the more popular British and European wheats is soft; that is, the grain is white and starchy when cut across; it is low in proteins and gluten; and when baked, it tends to give a badly risen loaf defective in colour. These defects were even more marked in the older wheats, especially the Rivet races. A hard wheat is generally red-grained

and shows a flinty and translucent surface when cut, but this is not universal, for some white-skinned, starchy-looking wheats show strength when baked. The hard wheats of Canada vary in origin, but the better-known ones are derived from Fife, a wheat from Galicia introduced into Canada towards the end of last century. This has been improved chiefly with a view to earlier ripening in the North-West, and races such as Preston, Percy, Huron, hybrids between Red Fife and another Russian wheat, have rapidly found favour. In later years Marquis (Red Fife × Hard Red Calcutta) has become prominent.

The hard wheats of the United States were also mixed originally, but improved races, including Minnesota, have been isolated. Many of the American varieties were originally obtained from Russia and other parts of Eastern Europe, and some of them were Durum wheats. This strain has been still further improved by hybridization, and new hard wheats are appearing frequently.

The defect of these excellent baking wheats from the British point of view is the low yield. The plant of most hard wheats has a thin straw, few tillers, and a lax meagre-looking ear, so that a comparison alongside of English varieties is not in their favour, though the yield of grain is higher than might be expected from their appearance in the field. The problem of obtaining a hard wheat with good baking qualities, combined with a high yield under British conditions, has led to considerable activity amongst plant-breeders, and at the present time varieties such as Biffen's Yeoman (Fife × Browick) are being grown and tested.

THE WHEAT CROP

By A. W. OLDERSHAW, M.B.E., B.Sc.(Edin.), N.D.A.

Wheat is by far the most valuable plant in the world. It is the main source of food for modern Europe, for much of Asia, for America, and Australia.

It is one of the ironies of history that no record should exist of the discovery of wheat, nor of the name of that great benefactor of the human race who sowed the first crop and reaped the first harvest. In the words of M. Henri Fabre, " History . . . celebrates the battlefields whereon we meet our death, but scorns to speak of the ploughed fields whereby we thrive . . . it cannot tell us the origin of wheat ".

The ancients described wheat as a gift of the gods, whilst the Chinese also considered that it came direct from heaven. Osiris was the intro-

ducer of wheat according to Egyptian mythology, whilst the Greeks ascribed its coming to the agency of Demeter and Tryptolemus. Demeter was worshipped at Athens and Eleusis, where every year the fields were solemnly ploughed in the memory of the first sowing of wheat.

As is well known, wheat has been found in the sarcophagi of Egyptian mummies, and some have the erroneous idea that this grain is capable of germination. It has been found in tombs of the First Dynasty, which probably dates back six thousand years.

The cult of the goddess Demeter was introduced to Rome from Greece, but her name was changed to Ceres, and a temple was raised to her on one of the seven hills. The country people especially worshipped the goddess and offered her the first fruits of harvest.

Professor Buller[1] in his *Essays on Wheat* gives an account of the discovery of the wild wheat of Palestine. He states that Körnicke identified a plant of wild wheat amongst some dried specimens of wild barley gathered from the slopes of Mount Hermon.

In 1905, Aaron Aaronsohn, director of the Jewish Agricultural Experiment Station at Haifa, in Palestine, rediscovered the plant. Subsequently Aaronsohn's observations were confirmed by Mr. O. F. Cook[2] of the United States Department of Agriculture, who found the wild Triticum widely distributed on the slopes of the Anti-Lebanon range of mountains. Cook found wild wheat growing amongst stones and boulders, quite obviously able to hold its own in competition with other plants, like any other truly wild species.

Of the steps by which man gradually brought wheat into cultivation and selected and improved it, little is known. The early improvers of wheat appear to have gone down to their graves unhonoured and unsung, and until comparatively recent times, little or no care was taken to preserve the history of the very numerous varieties of wheat which have come into existence. We know the names of a few old English wheats, such as Rivet and Lammas, but of the numerous varieties which must have been grown in this country during mediæval and more modern times very little information is available.

Climate for Wheat

Wheat is on the whole well suited for cultivation in the British Isles, especially in the southern and eastern portions of them. The climate of the south of England, the Midlands, and the Eastern Counties, as far north as Yorkshire, suits it admirably.

[1] *Essays on Wheat*, Professor A. H. R. Buller, Professor of Botany at the University of Manitoba. Published by the Macmillan Company, New York.

[2] See O. F. Cook, *Wild Wheat of Palestine*.

The area of wheat in Scotland and in Wales is comparatively small, as experience has shown that other cereals succeed better, especially in the later and damper districts. In the eastern and drier parts of Scotland, however, excellent crops are grown.

In Ireland, before the Great War, very little wheat was grown in Ulster, and the climate is not very well suited for it, being rather too cool and moist. In Leinster and the eastern and southern parts of Ireland generally, excellent crops may be grown, and the idea which prevailed at one time that the climate of Ireland is not well suited to wheat growing is undoubtedly a delusion as far as the eastern and southern districts of that country are concerned.

Wheat is a wonderfully hardy plant and will succeed under a great variety of climatic conditions. It requires, however, a fairly high late summer temperature, and not too heavy a rainfall, to enable it to ripen properly. The dry and comparatively sunny climate of the east and south of England undoubtedly suits it admirably.

It likes a dry atmosphere during the summer, and its extensive root system enables it to gather the moisture it requires from that accumulated in the soil and subsoil during the winter months.

In arid countries, moisture supply is often the limiting factor to the crop of wheat obtained, but though it sometimes happens on light soils in the drier districts of England that the crop is seriously reduced by drought, taking England as a whole, it is not very often that wheat is seriously affected by lack of moisture. The old saying "Drought never brought dearth to England" is very near the truth, but on the other hand, too much moisture and a lack of sunshine frequently reduce the yield of the British crop.

Wheat is a lover of sunshine and warmth, and it often happens that it goes yellow and unhealthy, especially in May, on heavy soils, owing to too much rain. In many cases, no doubt, this yellowing is actually due to lack of available nitrogen, which in turn is often due to the wet and cold condition of the soil preventing the nitrifying organisms from working actively.

Heavy rainfall during the winter months is also harmful, in that it washes out the nitrates from the soil and also prevents, to some extent, the formation of an extensive root system. Shaw has shown that the average crop in England varies to a considerable extent according to the rainfall during the winter—the higher the rainfall the lower the yield.

We have seen that too much rain in May is particularly harmful. Wheat, however, likes a quantity of rain in early June, but heavy rain and cool weather in July and August delay ripening, whilst, of course, a spell of wet weather is disastrous at harvest-time.

During a very wet time, when the wheat is ripe but cannot be cut owing to the weather, the grain will sometimes germinate in the ear as

it is standing and thus become spoiled. It is the effect of climate in delaying ripening which prevents a more extensive growth of wheat in the northern portions of the British Isles.

Although a fairly high temperature is desirable for ripening, yet it not infrequently happens that, in the best wheat years, the temperature during June and July is below, rather than above the average.

In the case of winter wheat, a mild open winter without too much rain is best. Provided the wheat is protected by a covering of snow, a short spell of frost does it little or no harm, but prolonged spells of frost, accompanied by keen winds, are very harmful when there is no snow on the ground. This is especially the case when the frost comes late in the season, as was the case in 1917. In that year a considerable proportion of the wheat in the Midlands and north of England was badly thinned out by frost, and many farmers had to fill it up in spring with oats or barley.

Soils for Wheat

Wheat will thrive on a great variety of soils, in fact on almost any soil except a light sand, poor in lime. On this latter type of soil it is a mistake to attempt to grow it. For such soils, rye is the most suitable cereal for autumn sowing.

Good heavy loams undoubtedly suit wheat best, and these constitute the ideal wheat soils, but excellent crops may also be obtained on most heavy and medium soils and even on sticky and untractable clays, if thorough drainage can be provided.

In regions of low summer rainfall, strong loams suit wheat admirably, and on heavy soils wheat will often succeed remarkably well, even although very little organic matter is present. Autumn-sown wheat does not require such a good tilth as most farm crops; further, the heavy soil is also usually capable of retaining sufficient moisture for the wheat during the summer, so that two of the most important functions of organic matter in the soil—improving the texture and retaining the moisture—are less important in the case of wheat than of most crops.

Sir A. D. Hall and Dr. E. J. (now Sir John) Russell, at the British Association at Winnipeg in 1909, pointed out that at Rothamsted, where wheat has been grown for a long period with purely chemical manures containing no organic matter, no difficulty is experienced in getting a plant; the seed germinates and grows away freely.

At Saxmundham Experiment Station, where a number of the plots have received only chemical manures for twenty years, exactly the same is the case. Even on plots which have received annual dressings of nitrate of soda and muriate of potash—both of which manures have an

injurious effect upon the texture of a clay soil, such as that at Saxmundham—a plant of wheat has always been obtained.

Good crops of wheat may be obtained on medium and even on comparatively light loams, provided there is sufficient retention of moisture to prevent the plant being dried up in the spring and summer, but a light loam is usually somewhat unsatisfactory for wheat in the dry and warm climate of East Anglia, yet from soils of a similar character, very good crops may be obtained in a cooler and damper district, as, for example, in East Lothian.

Very light heath soils, such as those of Norfolk, have been found to give fair crops of wheat, provided they contain a sufficient supply of lime and enough vegetable matter to hold the moisture. If they are deficient in lime, that most important mineral must be added. If they are poor in vegetable matter, steps must be taken, by ploughing in green crops or by leaving the land down in temporary layers of grass, clover, lucerne, or sainfoin, to increase the supply.

On peaty soils wheat is apt to produce too much straw and too little grain; but this condition of things may, however, be improved by adding lime, phosphates, and potash to the soil.

Place in Rotation and most suitable Preparatory Crops

In Great Britain and Ireland wheat is frequently grown after a leguminous crop, such as clover, beans, or peas. It is also grown after mixtures of ryegrass and clover, known as "seeds" in certain parts of England. The Norfolk four-course shift—roots, barley, clover, and wheat—illustrates the position in the rotation which is occupied in this case.

In those parts of England where bare fallows are common, it is quite usual to sow wheat after the fallow. It is also quite usual to sow it after mangolds and potatoes, and occasionally after turnips carted off early.

In most districts wheat usually succeeds best after clover, but excellent crops are also obtained after seeds, either grazed or mown, and after beans. Red clover, whether cut for fodder twice, or once for fodder and once for seed, is regarded as a most valuable preparation for wheat, the land being ploughed in September or October after removal of the second crop.

White clover, whether grazed with sheep, or saved for seed, is also an excellent forerunner of wheat; while trefoil, whether grazed, mown for hay, or for seed, is likely to be followed by a good crop.

White clover or trefoil, being harvested or grazed early in the season, often permits of a "pin", bastard or half fallow being made after the

removal of the crop and before sowing the wheat. In this way, if a fine August and September should follow, a clean seed-bed may be secured for the wheat.

In some districts it is usual to allow the seeds, i.e. a mixture of red, alsike, and white clover with ryegrass, to remain down for two years. In the second year the field is grazed or mown early, and then steam-cultivated in June or July. In this way, also, a " pin " or half fallow is taken, and, given favourable weather, a clean seed-bed is obtained for the wheat which follows.

In other districts a mixture of white clover and ryegrass is sown as a one-year sheep pasture, and this is either grazed all summer and ploughed in early October for wheat, or, if the field is somewhat foul, it is broken up in July and fallowed.

Where wheat follows white clover, trefoil, or a seed mixture, and there is no " twitch " or " couch " grass present, and very few weeds of any kind, the land may be ploughed in August, and not properly fallowed. When this plan is adopted, the ploughing must be done very carefully, and a skim coulter used, so that no green material whatever is visible after ploughing is completed. The land is then allowed to lie, and is merely harrowed to keep it free from seed weeds, the wheat being drilled in October. In this way a " stale " furrow is secured.

If difficulty is found in keeping the surface free from seed weeds during late August and September, a disc harrow will be found very useful. In some districts and seasons this method is more likely to secure a good plant of wheat than if the land were fallowed or half fallowed. It must be remembered, however, that land should not be treated in the way described if there is any couch grass present.

When wheat follows beans, the bean stubble is usually ploughed as soon after harvest as possible. In this case there is often not very much time for cleaning the land before the wheat must be sown, although the introduction of tractors appears likely to modify farm practice to a considerable extent by enabling a farmer to get his ploughing done rapidly after harvest, and so take advantage of any fine weather for cleaning operations.

Pea or vetch stubbles (after peas or vetches grown for seed) are merely ploughed, and the wheat seed sown as in the case of bean stubbles; but when vetches are cut green for soiling, silage, or making into hay, an opportunity often occurs to make a half fallow.

Peas or vetches, on the whole, are not such a good preparation for wheat as clover or beans, possibly because they do not accumulate so much nitrogen or leave such a large root residue.

Mangolds and potatoes are both excellent preparations for wheat, as for these crops the land usually receives a good cleaning, together with liberal manuring and summer tillage, and the residue of the manure has an excellent effect upon the wheat.

In the case of potatoes, the land requires little further treatment after the potatoes are lifted. It is usually ploughed, but, although desirable, this is not always absolutely necessary, as wheat likes solid ground.

Mangold land is ploughed before sowing wheat. After mangolds, wheat may not produce very much straw, but it usually gives a good yield of grain.

Occasionally wheat follows swedes, and where they can be removed early enough this is quite a good practice, as the swede crop makes a good preparation for wheat. In this case, as with mangolds, the land is merely ploughed and then the seed is sown immediately.

As previously mentioned, wheat is often sown after bare fallow. It is, however, a rather remarkable fact that fallow wheat is somewhat uncertain. It often fails in the spring—becomes patchy and uneven—in a way that is very difficult to explain. Of late years the Wheat Bulb Fly has been responsible for much damage to fallow wheat. It is also the case that bare fallows sometimes get too " light " during the summer working, and do not afford quite the firm foot-hold that wheat requires. It is particularly important that the tilth should be firm below, and autumn cultivations should be directed to this end. It is also worth noting that after a bare fallow the land has not been exhausted of moisture during the summer to the same extent as if it had carried a crop; consequently, the autumn rains sooner render it thoroughly wet. In the case of heavy land this is a considerable disadvantage, as there is no condition more harmful to wheat than a soil saturated with moisture during the winter. On such soil it becomes what is known as " water slain ", i.e. it perishes from the waterlogged condition of the soil.

As has already been noted, wheat may be grown after almost any crop. In fact, at Rothamsted Experimental Station, in Hertfordshire, on heavy land, wheat has been grown on the same land for seventy-eight years, with only two seasons break for fallow.

At Woburn, in Bedfordshire, on light soil, forty-four crops of wheat were grown on the same land without any break.

At Sawbridgeworth Mr. Prout grew wheat almost continuously on the same land for nearly fifty years as a commercial proposition. (See Continuous Wheat Growing.)

During the War farmers were asked to grow as large an area of wheat as possible, and in many cases it was grown after other cereals for two or even three years on the same land. In one case, known to the writer, wheat was growing on a heavy land field in August, 1914, at the outbreak of the war, and this field was sown with wheat every year while the war lasted. The crop was sown before Armistice Day in 1918, so that the field grew six successive wheat crops. The land was generously manured with artificials, and the first five crops were good, but the sixth crop, owing to the season, was not so good.

Occasionally it may be good farming practice to grow wheat after wheat or after another cereal, but as a rule there is nothing gained in the end by doing this; and though it is quite evident that fair crops may be obtained if suitable manures are applied, on the whole it is better to grow wheat in rotation, as is usually done. The only possible exception to this is on very heavy clay land such as is to be found in the south of England. In such counties as Essex, Hertford, and Middlesex there often is a ready sale for the wheat-straw as well as for the grain. These heavy clay soils can be maintained in fertility for a long period by comparatively inexpensive dressings of artificial manures. In the autumn such land can usually be tilled quite easily with the aid of the steam plough and cultivator, and there is really no reason why wheat should not be continuously grown under these conditions.

With skilful management, a bare fallow would rarely be necessary, but should weeds become evident, clover, or preferably trefoil, could be sown with the wheat, and cut for hay early the following season, after which a " pin " or partial fallow could be made. A crop of beans sown in rows, about 30 inches apart, and cleaned by horse- and hand-hoeing, would answer the same purpose.

Preparation of Seed-bed

Where wheat is grown on very heavy land, as is often the case, it is most important to make adequate arrangements for surface drainage in the autumn, even although the land may be under-drained.

On the stiffest of clays it may be desirable to plough the land in very narrow " stetches " or " lands ". In some districts stetches as narrow as ten furrows wide (about 8 feet) are made, and these, by providing frequent open furrows, enable the surface water to escape rapidly during the winter and ensure reasonably dry conditions for the crop. Where these very narrow stetches are made, it is usual to have a drill to take either exactly half or exactly a whole stetch at once, the stetches are arranged to suit the drill, and no corn is drilled in the open furrow. This practice has much to commend it on very sticky and impervious soil.

On rather more easily working land, the stetches may be made wider and the wheat drilled either up and down the stetches, or at right angles to the furrows—" over ward " as it is called.

On loams and lighter soils, no special precautions require to be taken, as, if under-drained, there is no danger from excess of water during the winter.

When ploughing for wheat, discretion must be used as to the depth of the ploughing. On deep loamy soils fairly deep ploughing may be practised, but where this is done, care must be taken to ensure that while

the top is loose, the bottom is adequately consolidated. On shallow clay soils it is no advantage to plough too deeply, as wheat likes a solid bottom. Moreover, harm results from bringing up the poor clay subsoil to the surface.

Wheat usually succeeds better when sown on land that has been ploughed some time, than on land only very recently ploughed. As the saying is, " Wheat likes a stale furrow ".

After bare fallows or half-fallows, a deep tilth, firm below, is generally aimed at. Such a seed-bed tends to prevent " root-fall " and the lodging of the crops, which is so likely to take place after bare fallow.

After a root or similar crop for which the land had already been deeply tilled, shallow ploughing for wheat is common, but in some cases excellent results are obtained by ploughing 8 inches deep and pressing afterwards.

After potatoes it is quite a common practice not to plough the land at all, but merely to cultivate and then drill in the seed.

The fact that a better " plant " of wheat is often obtained on the headland than in any other part of the field, is evidence of the kind of tilth required for wheat—firm underneath and loose on the top.

The implement known as a furrow-presser is very useful to obtain such a tilth, and it is widely used on chalk soils where it is difficult to get a firm seed-bed without some such steps being taken.

In Kent the method known as cartwheeling is practised, and the writer is indebted to Mr. G. H. Garrad, Agricultural Organizer for Kent, for a description of this. Mr. Garrad says the cartwheeling is really the same thing as furrow-pressing, with the exception that a single furrow slice is pressed at a time instead of four or five, as is done by a furrow-press drawn behind a steam plough. The description given by him is as follows:

" A horse plough is ploughing in a field, turning over a single furrow slice. Following the plough is a man in a cart; one wheel of the cart is on the unploughed land, the other wheel runs on the furrow slice just turned over by the plough and presses it firmly on to its neighbour. In this way the land is made much firmer, and there are no open seams left between the furrow slices as one often gets after indifferent ploughing; moreover, when the seed-wheat is broadcasted by hand on the ploughed land there is no waste through the seed dropping into an open seam and being buried too deep. The ploughed land is not harrowed until after the seed has been sown, and a turn of the harrows afterwards pushes the tops of the furrow slices into the grooves where the seed is lying and covers it."

This Kentish method is not well known in other parts of England, but in the absence of a better system it is worthy of serious attention by farmers who often suffer loss owing to their wheat land getting too

"light", and the plant "going off" in the winter and spring. It is worthy of note that this was the method adopted by Mr. Alfred Amos, of Wye, Kent, in sowing the Yeoman wheat from which he obtained the almost record yield of 96 bushels per acre.

Time of Sowing

Wheat is sown in autumn, in early winter, and in spring. The autumn wheat may be sown from late September until the New Year, but in so far as the experience of the writer goes in the Eastern and Midland Counties of England, it is only on the poorest and wettest of clays that September sowing is desirable. On most ordinary soils, October and November are excellent months in which to sow wheat, from the middle of October to the end of that month being the best period. At the same time, on really fertile wheat soils it may often be the case that wheat sown in November will yield better than wheat sown earlier. On these soils, early sown wheat produces rather too much straw, and, especially if sown thickly, is apt to produce a small ear and to go down. In the Western Midlands conditions seem to favour early sowing rather more than in the eastern and drier districts.

Experiments to ascertain the most suitable date for sowing are singularly few, but the following results were obtained in 1917–8 at the Harper Adams Agricultural College in Shropshire.

Time of Sowing.	Yield per Acre.	
	Grain.	Straw.
	Bushels.	Cwt.
30th September ..	34	43
13th October ..	30	39
6th November ..	20	36
20th November ..	Crop a failure.	

As a general rule the kind of weather which follows sowing is all-important and determines whether early or somewhat later sowing will prove the best. If winter sets in early and proves severe, early sowing will usually be best. On the other hand, with a very mild winter later sowing may be better.

In our uncertain climate, when the land is ready it is generally best to sow any time one has the chance after 1st October, except possibly on the most fertile of heavy loams. On very stiff soil, unless sowing is carried out when the land is in a suitable condition, weeks may elapse

before another opportunity occurs. The farmer who cultivates very heavy land usually favours early sowing, whereas the occupier of the better type of heavy loam often prefers to sow somewhat later.

In the eastern half of England, the rainfall is occasionally so low in the autumn that great difficulty is experienced in ploughing the land for wheat. This was the case in 1914, and again in 1919 and 1920, and observations made in those years show that where there is not sufficient moisture to germinate the grain a poor plant results, and the seed goes mouldy in the ground instead of germinating properly. This is especially the case where very little rain falls until December.

Where such conditions obtain, it is better in most cases to wait for rain rather than put the wheat in amongst the dry clods. The farmer, however, who farms very sticky land is in such cases in a dilemma, for if he sows early he may get a bad plant, and if he waits for rain the land may get so sticky that he is unable to sow at all.

The variety of wheat known as Rivet or Cone wheat should always be sown early—if possible by the end of September or early in October.

Quantity of Seed required

The quantity of seed required per acre varies considerably with the district and the time of sowing. Wheat sown early requires much less seed than if sown late. The average quantity is about 2½ bushels per acre for wheat drilled at the end of October, but 2 bushels, or even less, is sufficient if sown in the beginning of October, whilst 3 bushels should be allowed if the sowing is delayed until the beginning of December. Rather less seed is required on good land or where there is a good tilth and the seed can be covered well.

Under the poor and rather exposed conditions of the Downs, up to 3½ bushels per acre are sown, but over-thick seeding tends to weaken the straw. On the other hand, a very thin crop is likewise easily knocked down or " storm-broken ".

More seed is required when broadcasted than when drilled, as when the seed is broadcasted, a certain proportion is buried too deep or is left on the top uncovered, and is thus picked up by birds. Where 2 bushels are drilled, nearly 3 should be broadcasted, but much depends on soil, climate, time of sowing, and variety.

Very little experimental work has been done upon the quantity of seed required per acre, but the value of moderate seeding was demonstrated in a series of trials at Newport in 1913 and 1914, when the following results were obtained.

The seed was sown on 15th and 17th October, the variety being Browick.

Rate of Sowing.	Yield, 1913.		Yield, 1914.	
	Grain.	Straw.	Grain.	Straw.
	Bushels.	Cwt.	Bushels.	Cwt.
2 bushels per acre ..	45	41	47	47
$2\frac{1}{4}$,, ,, ...	43	40	47	45
$2\frac{1}{2}$,, ,, ...	46	42	47	49
$2\frac{3}{4}$,, ,, ...	46	48	42	48
3 ,, ,, ...	38	47	35	43

Under favourable conditions the best results are usually obtained by a moderate seeding, but, unfortunately, if the farmer decides to sow a small quantity of seed per acre the succeeding winter may be a hard and cold one, and he may find that his wheat is too thin in the spring.

Recent experimental work in Essex and Suffolk has shown that under favourable conditions much less than 2 bushels per acre may give a satisfactory plant.

On the other hand, a report, published by the Midland Agricultural and Dairy College, states that on the gravelly soil of one of the college farms it has been observed for a number of years that cereals do not stand the winter so well as on heavy soils near. An experiment was accordingly started in the autumn of 1920 with Yeoman wheat, varying quantities of seed were sown, and some of the plots were drilled in two directions to ensure better distribution. The following results were obtained in 1921:

Plot.	Seeding.	Drilling.	Yield in Quarters per Acre.
1	$1\frac{1}{4}$ bushels per acre	One direction	4·11
2	$2\frac{1}{2}$,, ,,		4·73
3	$3\frac{1}{2}$,, ,,		4·98
4	$4\frac{1}{2}$,, ,,		5·3
5	3 ,, ,,	Two directions	5·43
6	$3\frac{3}{4}$,, ,,		5·6
7	$4\frac{1}{2}$,, ,,		5·65

It would appear from the above table that comparatively heavy seedings produced a considerable increase in the yield, and that with the same seeding a greater yield was obtained when the seed was drilled in two directions, i.e. when there was a more perfect distribution of plants over the ground.

The report points out that these trials were carried out during only

one season, hence it is unwise to form very definite conclusions from them.

It appears probable, however, in view of the good results obtained in Essex and Suffolk from light seeding on good heavy wheat land, that the ideal quantity of seed varies considerably with the nature of the land, as well as with other factors.

It is hardly necessary to point out that the quantity of seed required per acre will vary according to the percentage germination of the grain. Further, it is a wise proceeding to reject any damaged sample of seed wheat, as, even although the percentage germination may be fairly high, it often happens that the plants produced from such damaged grain are weak and unsatisfactory. Samples of wheat which have heated in the sack or stack are particularly liable to cause loss owing to unsatisfactory germination, and very often there is little in their appearance to indicate their unsatisfactory character. The only safe way is to test the seed for germination before sowing, and to reject all unsatisfactory samples.

Before sowing the grain it is usual to "pickle" or "dress" it, as a preventive against bunt and smut. (See Parasitic Fungi.)

In districts where rooks or crows are troublesome, it may also be desirable to dress the seed with some protective preparation. Some of the preparations on the market have been found to affect adversely the germination of the grain, and care should be taken not to select one of these.

After drilling or sowing the seed, it is a wise precaution to fix up a scarecrow or a dead rook in the field to keep away the birds.

Manner of Sowing

Drilling.—After ploughing, and before drilling in the seed, the land is rolled if dry enough, and is then worked down by heavy and light harrowings or by both. Rolling is impossible if the land is at all wet, especially on heavy land.

The wheat is drilled in rows from 7 to 10 inches apart. The rows should be perfectly straight, otherwise horse-hoeing in spring is impossible. In view of this, a steerage drill is to be preferred, although skilled men will do wonderfully good work without a steerage attachment. If the land is cloddy it is difficult to make the rows perfectly straight.

After drilling, the land is again harrowed, to cover up any seed that is on the top, but it is not necessary to reduce the surface to a fine tilth—in fact on most soils it is an advantage to leave it a little rough, as the small clods serve to protect the wheat from the cold winds in winter, and they also prevent the soil from "caking" on the surface after heavy rain. In spring the clods crumble down when rolled and harrowed, and so make a nice layer of fine soil on the surface.

If too fine a surface is obtained in autumn, some soils are very apt

to cake or run together during the winter and so produce a condition which is unfavourable to growth.

Wheat may be drilled when the land is comparatively wet and sticky —in fact, as previously mentioned, it is undesirable to put wheat in when the soil is too dry. This was demonstrated in the autumn of 1920, when very little rain fell in October and November over large areas in England, and fields of wheat were sown with a dry seed-bed. Much of the seed became mouldy instead of germinating, so that when rain finally fell in early December a very unsatisfactory plant of wheat came up, and in many cases redrilling in the following spring, with either spring wheat, barley, or oats, was necessary.

On the other hand, if the land is too wet, the coulters of the drill will not penetrate the soil, and it is difficult to cover the seed.

Broadcasting.—Wheat may be broadcasted on the ploughed land and then harrowed in, but this should only be done when the land has been ploughed in such a way as to leave a good seed-bed and plenty of crest for the harrows to break down and cover the seed. It is usually held to be useless to sow wheat unless it can be sufficiently covered, for, even if it is not taken up by birds, it does not get a satisfactory root-hold, and consequently the crop is a failure. Of late, however, a method has arisen of sowing wheat near the surface with a special drill. (See Depth of Covering.)

On very stiff, heavy land, it not infrequently happens that wet weather prevents drilling in the autumn, and that the only possible method is to broadcast and cover the seed as well as possible. Under such conditions the wheat is " dragged " in by heavy harrows or " duckfoots ". This is often done when the land is very wet and sticky, and though the whole operation may seem to the uninitiated to be very unsatisfactory, nevertheless wheat put in under these conditions is more likely to give a satisfactory crop than wheat drilled in a seed-bed that is too dry.

In large areas on the Downs wheat is broadcasted by a machine fitted with cultivating attachment, which breaks up the surface and covers the seed.

The Kentish cart-wheel method of providing a good seed-bed has been previously referred to, and there can be no doubt that very heavy crops are secured in this way. The seed is broadcasted and falls into a firm, wide groove over which it is well distributed. The ample space between the rows very possibly makes for sturdier, better standing plants than are obtainable in a narrow groove with the seeds near together and the intervening drill spaces only a matter of 6 inches or so wide. This point, however, is one which badly needs investigation.

On wet, heavy clays wheat is often the most reliable crop, and it is important to get in as large an acreage as possible. On such land it is quite customary to resort to expedients to get the crop in, which, to those

not familiar with the special conditions, would appear to be somewhat bad farming. Thus, on broken ground after fallow, potatoes, or peas, wheat is quite often ploughed in. The plough is set to take a furrow of only 3 inches in depth, the wheat is broadcasted and then turned in. If care is taken not to cover too deeply, it comes up quite well; in fact, this is a fairly good way of sowing wheat, much better than trying to cover it by sowing after ploughing and harrowing when the surface is sticky.

Unless wheat can be properly covered, either when drilled or broadcasted, it is far better to postpone the operation until conditions are more favourable, whilst if the wheat is being well covered there is no danger in going on with the work even if the land seems to be in a sticky condition.

Depth of Covering

Very little information is available as to the depth at which the seed should be deposited. Most drills leave it at a depth of about 2½ inches, but wheat succeeds quite well even when sown 3 inches deep as in "ploughing in". A drill has recently appeared of which the principle is to distribute the seed thinly (about 1½ bushels per acre) by coulters 3 inches wide and 9 inches apart. These coulters barely enter the ground, but the seed is covered over by two cultivating attachments fixed behind each coulter, the effect being to leave the surface of the field in slightly raised ridges. When this method of seeding is adopted the surface tilth required is much finer than that usually considered desirable for a crop which is to stand the winter, but no serious "capping" results, and such as is found gives readily to a set of light parmiter harrows run over the wheat in spring.

Fertilizers are deposited in the rows a little deeper than the seed and do not come into direct contact with it, and the result from this method of sowing, as seen in a field near Chelmsford, was a wonderfully strong, upstanding plant with numerous tillers all of the same length and with long, full ears of equal size. The appearance of the crop generally was in marked contrast to adjoining lots sown by other drills; the straw was finer and weaker, the ears shorter, and many tillers only half developed.

Examination of the root systems of the several lots also disclosed interesting differences. In the case of wheat sown in the ordinary way there were two tiers of roots on each plant, one well below the surface level, the other near the surface. In the case of the new drill referred to, all the roots were practically at the surface; they were stronger and longer, and the topmost were practically surface anchors after the manner of tree roots. Special shallow-sowing coulters have also been manufactured to affix to any drill; these coulters leave the seed in a row 3½ inches

wide and ½ inch to ¾ inch deep. They are manufactured by B. T. C., Ltd., Millbank, Bradfield, Manningtree, Essex. This method of drilling, like many other problems connected with wheat growing, requires much further investigation, and the present state of our knowledge does not warrant a decided opinion being given either for or against it. In Essex this question is arousing much interest, and is being carefully studied by the staff of the Institute of Agriculture at Chelmsford. Mr. John Hepburn, of Bradfield Hall, Manningtree, has taken a prominent part in advocating shallow sowing.

Treatment during Growth

On heavy land, immediately after the wheat is drilled or sown and the final harrowing has been given, water furrows should, where required, be made by the plough in such a way as to lead the surface water to the lowest part of the field, and then into the nearest ditch. The outfalls of these will usually require to be frequently cleared by hand to enable the water to flow freely. After the water furrows have been made, the wheat is left alone until spring. On light and loamy soils it is not usually necessary to arrange for surface drainage unless in districts of heavy rainfall.

As soon as the land is dry enough in spring, wheat should be rolled, harrowed, and horse-hoed. These operations may be performed once or twice if thought necessary. The harrowing breaks the winter crust and kills large numbers of seed weeds, and leaves a loose coating of soil around the roots of the plants. A good harrowing greatly benefits wheat and causes it to tiller well.

Opinions differ as to the order in which the rolling, harrowing, and horse-hoeing should be done; very often rolling should not be the final operation, but it proves better to harrow or horse-hoe last, as these operations leave a fine tilth on the surface to protect the land from drought.

If the wheat has been drilled in straight rows, it should be horse-hoed once or twice. If the tines of the horse-hoe are set carefully, they cut out all the weeds which are not actually in the rows, and a subsequent harrowing pulls out many of those in the rows. Horse-hoeing is of course impossible where the wheat has been broadcasted.

If there are any docks present they should be removed by hand as early as possible in spring. In some parts of the country a short docking iron is used to place under them and so lever them out of the soil. If this is done they can be removed before the ground gets hard, and before they begin to run up to seed. They should be gathered and carted off the field. In some districts docking is not done until the plants begin to run to seed. This method has the disadvantage that the docks have then

taken much plant food from the soil. Further, in wet weather it is very unpleasant to work amongst the wheat when it is up to the knees.

On rich land, should the wheat be too forward and flaggy in March and early April, it will benefit considerably by light grazing with sheep. This reduces the danger of the crop becoming laid and also promotes " tillering ".

In addition to harrowing, horse-hoeing, and rolling, wheat is very often hand-hoed, especially when it has been drilled. Although of late years the operation has become less common owing to scarcity and dearness of labour, there can be no doubt as to the benefit derived from it.

Where wheat has been broadcasted it is difficult or impossible to hand-hoe, but any thistles present should be " spudded ", and all docks pulled out. After this the wheat requires no further treatment until harvest.

Spring-sown Wheat

It is not often that the state of the land permits of much wheat being sown in December and January on heavy land, and it is usually stated to be undesirable to drill wheat in these months. Nevertheless, if the land is dry enough, farmers who have not been able to sow earlier generally take the chance and put it in, and although growth is slow the final result is often better than if they waited. This applies more particularly to heavy land; on medium and light loams there is usually a chance to sow at a more favourable time, but heavy land farmers learn from experience that they must sow when the land is fit, and if they miss a chance it may never recur.

Wheat sown after the end of January must be regarded as spring wheat, and as there is not the same risk of severe frosts, wheat sown after that date should be given a finer tilth than autumn-sown wheat. More seed also is required as tillering does not take place to the same extent, and at least 3 bushels per acre should be sown.

After the beginning of February it is better on the whole to sow one of the French wheats such as Red Marvel; and though some wheats, such as Little Joss, Squarehead's Master, and white wheats of the Wilhelmina type, will answer if sown in February on good land, in general, French wheats are safer.

After the beginning of March it is almost essential, if it is desired to sow wheat at all, to sow either French wheats such as Red Marvel or April Spring Bearded. If an autumn variety is sown late in spring, say after the middle of February, it very often proves unsatisfactory and sometimes fails to ripen at all.

Spring wheat is not generally so satisfactory in this country as winter

wheat in point of yield. Still, there are numerous cases in which Red Marvel sown in February has given a yield approaching, if not equalling, autumn-sown wheat.

In the case of spring wheat a finer surface tilth is necessary than for autumn-sown wheat. After ploughing, if the furrow is fresh and loosely packed, a heavy roller may be run over to consolidate the land, after which the harrows are freely used to still further consolidate the soil, while reducing the surface to a fine tilth. Spring-sown wheat also requires fairly generous treatment in the matter of manure in order to encourage growth and hasten maturity.

Trials conducted in Essex in 1911 and 1912 to test the effect of sowing spring wheat at different dates showed in both years a very marked superiority in favour of early spring sowing. Red Marvel was the variety under trial, and February sowing proved much better than March sowing, whilst the yield obtained from April sowing was the poorest.

Harvesting

In the best wheat-growing districts of England, wheat, in an average season, usually comes into ear in June or early July, and ripens in August. It is a very simple matter for the experienced farmer to tell when the wheat is ripe; indeed, it should always be cut as soon as the grain is quite firm. If cut too early, the grain shrivels up and a reduction in yield results. On the other hand, if cutting is delayed too long, serious loss may result from shelling of the grain by high winds or during cutting.

It often happens in practice, however, that all the wheat ripens about the same time, and consequently the entire crop cannot be cut just when the grain is at the best stage, as some fields must be taken a little early or others are still uncut several days after they are ripe. Unfavourable weather also often delays operations and causes part of the crop to get over ripe; and when cutting is delayed for any reason there is usually some loss of grain from shelling.

In England wheat is generally cut with the binder, though in some districts the side-delivery reaper, the back-delivery reaper, and even the scythe, are still used. Very little wheat, however, is cut with the scythe nowadays, except when the crop is very badly laid; even then it is often possible to cut it with a machine, by meeting the crop as it is laid and cutting only one way.

Of late years scarcity of labour has compelled most farmers to cut with the binder, no matter how badly their crops have been laid, and where care is taken it is wonderful what good work can be done.

After cutting, the wheat is "stooked" or "shocked" exactly as with other corn crops, and, in most districts, eight to twelve sheaves are placed

in one stook. In the northern districts the stooks may be headed or "hooded", but most wheat-growing districts are comparatively dry, and this precaution is not often taken.

In dry districts, when the weather at harvesting is specially favourable, wheat that is free from grasses, clovers, weeds, &c., is often carted a few days after it is cut without having been stooked.

Wheat does not require to stand long in the stook in good harvest weather, provided it is ripe when cut, and clean. Under such conditions the crop may be safely carted a few days after cutting. On the other hand, if the straw is at all green when cut, or if there is much grass or other rubbish in the butts of the sheaves, the wheat must be left in the field until the green stuff is quite dead, or the stack will heat and the grain will be damaged.

When wheat-straw is clean, what to the outsider might be considered as risks may be taken in harvesting. For example, wheat that has once been thoroughly dry and fit to cart may be safely stacked, although the chaff is slightly damp from dew or a recent shower. Practical men, in the various districts in which wheat is grown, are usually quite well acquainted with the extent to which it is possible to take such risks without damaging the wheat in the stack. They also know that what is quite safe in districts of low rainfall would be unsafe in a moister district; at the same time it should be borne in mind that wheat that has once been dry may be safely carted in a condition which would completely spoil oats or barley.

When wheat is carted in a comparatively damp condition the stack should be allowed to stand until spring before threshing, when the grain will usually come out of it quite hard and dry. When it is desired to thresh the wheat during or shortly after harvest, it should only be carted in a thoroughly dry condition. If the crop is to be threshed out of the stook without stacking, the grain must be hard and dry at the time of carting. The condition of the straw, however, is of less importance, and the sheaves may contain some green stuff which has not had time to become dead and cured without any harm resulting. In fact a little green stuff amongst the threshed straw will cause it to heat slightly, and this may make it more palatable as fodder.

In very showery and mild weather the grain germinates readily when the crop is in the stook, and may be partially or even completely spoilt. Certain varieties of white wheat grow in this way rather more readily than the red wheats.

In typical wheat-growing districts the sheaves are stacked in large stacks or ricks, with either circular or rectangular bases, as much as 10 to 12 acres or even more of an average crop being placed in a stack. In damper and more northern districts the stacks are usually made very much smaller.

When stacking wheat, if care is always taken to keep the centre of the stack well up and rather higher than the outside, little damage will result even if rain falls before the stacks are thatched, as when the centre is kept firm and well up rain does not enter so readily. If the sheaves are properly arranged, the water trickles down the straws, all of which should point downwards and outwards.

Where wheat stacks are erected under Dutch barns, however, less care is necessary, but even then the outside sheaves should have the heads higher than the butts or rain may trickle in.

In the drier districts of England some wheat is often threshed direct from the field. Where this can be done there is a considerable saving of labour, as the crop is handled only once instead of twice and the trouble involved in stacking and thatching is avoided. Even in a favourable season, however, the whole crop cannot as a rule be threshed at harvest. Where the grain is to be kept until spring or early summer, there is less risk of damage when kept in the stack than when kept in any other way, provided the stacks are properly thatched and kept free from rats and mice.

Thatching

The thatching of the stacks or ricks is performed in various ways in different parts of England, but, provided the work is done in such a way that the stacks are kept dry, the actual method of thatching adopted is not a matter of primary importance. Good farmers take much pride in having their stacks thatched neatly, and a stackyard full of well-thatched stacks is undoubtedly a very pleasant sight.

In some districts, especially in the Midlands, the roofs of the stacks are temporarily covered with "battens" or bundles of straw. These are kept in place by means of thatch pegs, i.e. straight sticks about a yard long and with pointed ends.

A large wheat stack can be covered with battens in a very short time, and, when the work is carefully done, the roof may be kept dry for a month or two until the stack can be threshed or permanently thatched. This system forms a very cheap and quick way of temporarily protecting stacks, and in some seasons, especially in the case of badly built stacks, may prevent considerable loss owing to heavy rain falling immediately a stack is erected and before there has been time to thatch it. Thus in 1912 there was a very heavy rainfall at the end of August, amounting to several inches in a day, in many parts of East Anglia. Much of the wheat was in stack at the time but was unthatched, and the rain in many cases penetrated half-way through the stack, so that farmers had to take their stacks to pieces again. This would not have been necessary had the stacks been covered with battens.

Threshing and Utilization of Produce

A big proportion of the wheat grown in Great Britain and Ireland is threshed by threshing-machines driven by steam power or by tractors. The machines in use in most districts thresh from 50 to 80 quarters in a day. In a few localities small horse-power mills are still to be found, but the quantity of wheat threshed by these is almost negligible.

In many cases, owing to the high standard of efficiency of modern threshing-machines, winnowing is unnecessary, and the wheat is often loaded straight from the threshing-machine on to wagons and delivered to the nearest station or mill.

The modern threshing-machine takes out practically all weed seeds, and also separates the tail corn or small grains from the large corn. The tail corn is usually retained at home by the farmer for the feeding of poultry.

Wheat-straw is used on the farm chiefly for litter; it also makes excellent thatch, and occasionally, when other straw is scarce, it is cut up or chopped, mixed with pulped roots, and fed to stock.

It is also frequently fed to store stock in yards, when they pick it over and eat the most palatable portions, the remainder being trampled into manure. As a food for stock it is decidedly inferior to oat-straw, but is quite useful for store stock receiving a maintenance diet.

Wheat chaff is also mixed with roots and fed to stock; it is useful for that purpose, although its feeding value is not very great.

Of the products of the grain, the flour is used almost exclusively for human food. The bran, pollards, middlings, and various other milling offals, which have different names in different localities, are very valuable as animal foods.

Manuring

Much of our knowledge of the manurial requirements of wheat has been obtained from Rothamsted Experiment Station.

On the Broadbalk field at Rothamsted, wheat has been grown continuously since 1852, and certain of the results are given below.

These classical experiments illustrate the general principles of and give valuable guidance in manuring wheat. They show the beneficial effects derived from farmyard manure, and the results obtained by the use of artificials. The plot which has received no manure for 60 years is also of much interest.

The plots manured with mineral manures alone show that these ingredients are comparatively ineffectual on wheat without nitrogenous manures, but the addition of a nitrogenous manure (in this case ammonium

Plot.	Manuring per Acre.	Average Yield for 61 years, 1852–1912.	
		Dressed Grain.	Straw.
		Bushels.	Cwt.
2	Farmyard manure, 14 tons	35·2	34·8
3	Unmanured	12·6	10·3
5	Minerals, i.e. $3\frac{1}{2}$ cwt. superphosphate (37 per cent), 200 lb. sulphate of potash, 100 lb. sulphate of soda, and 100 lb. sulphate of magnesia	14·5	12·1
6	Ammonium salts 200 lb. (containing 43 lb. nitrogen), and minerals as plot 5	23·2	21·4
7	Ammonium salts 400 lb., and minerals as plot 5	32·1	32·9
8	Ammonium salts 600 lb., and minerals as plot 5	36·6	41·1
10	Ammonium salts alone (400 lb.)	20·0	18·4
11	Ammonium salts 400 lb., and $3\frac{1}{2}$ cwt. superphosphate	22·9	22·3
12	Ammonium salts 400 lb., and $3\frac{1}{2}$ cwt. superphosphate, and 366·5 lb. sulphate of soda	29·1	28·0
13	Ammonium salts 400 lb., $3\frac{1}{2}$ cwt. superphosphate, and 200 lb. sulphate of potash ..	31·0	31·5
14	Ammonium salts 400 lb., $3\frac{1}{2}$ cwt. superphosphate, and 280 lb. sulphate of magnesia ..	28·8	28·0
15	Ammonium salts 400 lb. in autumn, and minerals as plot 5..	29·9	29·7
19	1889 lb. of rape cake (containing nitrogen equal to that in 400 lb. ammonium salts)	25·4	25·7

salts) to the minerals has a remarkable effect upon the crop, the varying quantities of ammonium salts added to plots 6, 7, and 8 resulting in a gradually increasing yield. It is noteworthy that whilst the first 200 lb. of ammonium salts increase the yield by 8·7 bushels, the second 200 lb. increase it by 8·9 bushels—practically the same, whilst the third 200 lb. only gives a further increase of 4·5 bushels.

Ammonium salts alone, without minerals, are not so satisfactory, whilst even the addition of superphosphate fails to give as good a yield as when all the minerals are applied. The addition of both phosphates and potash, however, to 400 lb. of ammonium salts brings up the yield almost to the level of the complete minerals and ammonium salts. Sulphate of soda and sulphate of magnesia, applied to plots 12 and 14 respectively, fail to fully take the place of sulphate of potash.

Other important results are that ammonium salts applied in autumn do not prove as effectual as when applied in spring, and that rape-cake alone, without minerals, proves much more satisfactory than ammonium salts alone.

The Royal Agricultural Society of England has for more than forty years conducted experiments on the manuring of wheat on their farm at Woburn, in Bedfordshire. These experiments somewhat resemble those at Rothamsted. The wheat has been grown continuously, and in many cases the same manures have been applied annually. The soil, however, at Woburn is light, whereas that at Rothamsted is a heavy loam. Further, at Woburn the soil does not contain any considerable store of lime, and one of the most striking results of the experiments there is the exhaustion of the soil of the small stores of that constituent present by the continued application of sulphate of ammonia.

As illustrating this point it may be mentioned that whilst in 1918 one of the no-manure plots gave 13·6 bushels of wheat per acre, the plot which had received a continued application of sulphate of ammonia gave no crop at all. The application of 2 tons of lime in 1897, however, was sufficient to rectify the shortage caused by the use of sulphate of ammonia, and the crop obtained on a plot which received this and sulphate of ammonia gave 19·6 bushels in 1918.

Again, taking 1918 figures, we find that nitrate of soda alone did not exhaust the lime in the soil, a plot receiving this manure, containing nitrogen equivalent to that in 25 lb. of ammonia, giving 17·6 bushels.

The addition of mineral manures alone—3 cwt. of superphosphate and ½ cwt. of sulphate of potash—gave 14·6 bushels, i.e. about the same crop as one of the no-manure plots. When, however, nitrate of soda was added to the mineral manures, the crop rose to 22·3 bushels, whilst an annual dressing of sulphate of ammonia, minerals, and 1 ton of lime (in 1905) resulted in a crop of 28·3 bushels per acre.

Rape dust, containing nitrogen equivalent to that in 25 lb. of sulphate of ammonia, gave 28·1 bushels in 1918, whilst farmyard manure, containing nitrogen equal to 100 lb. of sulphate of ammonia, gave 26·5 bushels.

Another series of experiments which are worthy of note are those conducted at Saxmundham, in Suffolk, by East Suffolk Education Committee. These experiments resemble those at Rothamsted and Woburn in that the same manures are applied annually. At Saxmundham, however, there are four sections of a field, and each section is farmed on the four-course rotation, so that every year we have leguminous crops, wheat, roots, and barley, all manured in the same way.

The experiments have been conducted for twenty years. The soil is a chalky boulder clay. The following are the average figures for the wheat crop for the years 1909–18 inclusive:

Manuring of Wheat at Saxmundham Experimental Station

Average Yields, 1909–18

Plot.	Annual Manuring per Acre.	Grain.	Straw.
		Bushels.	Cwt.
1	6 tons farmyard manure	24·1	34·9
2	4 cwt. bone meal	22·6	28·5
3	2 cwt. nitrate of soda	23·0	31·8
4	2 cwt. superphosphate (30 per cent) ..	20·3	25·9
5	1 cwt. muriate of potash	17·4	21·3
6	No manure	17·5	21·3
7	2 cwt. superphosphate, 1 cwt. muriate of potash	20·2	25·4
8	2 cwt. nitrate of soda, 1 cwt. muriate of potash	23·8	34·3
9	2 cwt. nitrate of soda, 2 cwt. superphosphate	28·7	39·2
10	2 cwt. nitrate of soda, 2 cwt. superphosphate, 1 cwt. muriate of potash ..	26·6	40·5

These results show that manures containing one manurial ingredient only, whether nitrogen, phosphates, or potash, give relatively unsatisfactory results; where, however, nitrogen and phosphates are combined, as in plot 9, the results are quite good; in fact, a heavier crop is obtained from this plot than from farmyard manure. Phosphates and potash without nitrogen, or nitrogen and potash without phosphates, are on this soil relatively unsuccessful. The addition of potash to nitrogen as nitrate of soda and phosphates has not resulted in an increase of the wheat crop.

The experiments of which a short summary has been given indicate the general principles of the manurial treatment of wheat. It is evident that on normal soils both phosphates and nitrogen are required, and either of these plant foods without the other gives relatively unsatisfactory results. The question as to whether the addition of potash is desirable is more doubtful. In ordinary farming where the land receives a dressing of farmyard manure from time to time, it is probable that it is unnecessary to add potash in the form of artificial manure for wheat, especially in the case of wheat soils which are fairly heavy, as such soils usually contain considerable stores of available potash. On light soils, however, potash is generally profitable even for wheat.

If the soil is sour owing to lack of lime, it is essential to apply that substance, otherwise good results will not be obtained.

It is evident from an examination of the experimental work at the

three stations referred to, that they provide unsurpassed material to illustrate the general principles of the manurial requirements of wheat. It may, however, be argued that they do not provide information, such as the ordinary farmer requires, as to the increase likely to be obtained by the use of manures on wheat under ordinary farming conditions.

Experiments in which fields under ordinary conditions have been manured in various ways for the wheat crop and the results tabulated have been conducted to a very limited extent in this country, and it is a great pity that it should be so, for there can be very little doubt that if a few such experiments had been conducted annually in every county in this country during the past twenty years, the knowledge of the manuring of wheat possessed by the agricultural community would be greater than it is, and in all probability the quantity of artificial manure used for that crop would be much larger.

In Ireland some work of this kind has been done under the auspices of the Irish Department of Agriculture. Thus, in 1920, experiments were conducted at twenty-two centres in that country by the county agricultural instructors, with the object of ascertaining the increase likely to result from the application of sulphate of ammonia and nitrate of soda under ordinary farming conditions. The crops selected for experiment were neither very good nor very poor.

The two manures mentioned were not as a general rule sown at the same centres, so that no comparison is made between them; both manures, however, gave considerable increases. At eight centres 1 cwt. of nitrate of soda per acre gave an average increase of 6 bushels of grain and 7 cwt. of straw; whilst at fourteen centres $\frac{3}{4}$ cwt. of sulphate of ammonia gave an average increase of $7\frac{3}{4}$ bushels of grain and 9 cwt. of straw. The report states that the extra yield of straw would, in normal circumstances, be sufficient to defray the cost of the manure used.

The experiments clearly demonstrated that the application of a nitrogenous manure to wheat in spring may effect a considerable increase in crop yield, and will, in most cases where the crop is backward, prove extremely remunerative.

The experiment was not designed to compare the two manures mentioned, and, from the figures available, it must not be concluded that $\frac{3}{4}$ cwt. sulphate of ammonia will increase the yield to a greater extent than 1 cwt. of nitrate of soda. Both manures proved quite satisfactory.

One of the cheapest and best ways of manuring wheat is to manure it indirectly through a preceding leguminous crop.

In many parts of the country it is becoming the practice to apply a dressing of basic slag or superphosphate to clover, resulting in a good crop of clover and a large amount of clover root residue being left for the succeeding wheat crop. Of the soundness of this principle there can be no doubt, and by this means full advantage is taken of the nitrogen-collecting

powers of leguminous crops. This system may be applied, not only where clover is grown, but beans, peas, lucerne, sainfoin, tares, and, in fact, all leguminous crops may be manured with phosphates, or phosphates and potash in the case of lighter land, with considerable benefit to the fertility of the land and consequently to succeeding crops.

Very few direct experiments on this subject are available; the following, however, conducted at Saxmundham by the writer, give an indication of the kind of result which may be expected on poor heavy land.

Plot.	Manurial Treatment in the Winter of 1913–4.	1914. Clover, Cut Twice.	1915. Wheat, no Manure to any Plot.	
			Grain.	Straw.
		Cwt.	Bushels.	Cwt.
1	10 cwt., basic slag[1] 30 per cent ..	53	31·7	34·3
2	5 " " " ..	51	26·7	34·3
3	5 cwt., basic slag 30 per cent, 1 cwt. muriate of potash	53	27·9	35·3
4	No manure	39	19·7	36·4
5	4 cwt., superphosphate 30 per cent	56	25·4	37·1
6	4 cwt., superphosphate 30 per cent, 1 cwt. muriate of potash ..	60	23·5	38·2

It is quite evident from these figures that the extra nitrogen accumulated by the larger clover crop on all the manured plots, together with the residues of the phosphatic manures, influenced the wheat very considerably.

The following figures, taken from the rotation experiments at Saxmundham, also indicate that the character and manuring of the clover crop has a considerable influence upon the wheat following.

Plot.	Manuring per Acre.	Clover, 1903.	Wheat, 1904.	Clover, 1919.	Wheat, 1920.
		Cwt.	Bushels.	Cwt.	Bushels.
6	No manure	22	19	24·5	11·3
7	2 cwt. superphosphate, 1 cwt. muriate of potash	48	32	73·0	27·3
9	2 cwt. nitrate of soda, 2 cwt. superphosphate	47	28	53·0[2]	31·3

There can be little doubt that the comparatively heavy crop of wheat

[1] The basic slag used was of high citric solubility. [2] An irregular plant of clover.

obtained in plot 7, when compared with that on the no-manure plot, is largely due to the nitrogen accumulated by the preceding clover crop, which is very much heavier on plot 7 than on plot 6.

In 1917 very poor crops of beans were obtained on all these plots (owing to the severe winter of 1916–7), so that there was in this case little residue for the wheat following. In 1918 the wheat on plot 7 was no better, in fact, not quite so good as on plot 6.

Of late years a number of stiff-strawed varieties of wheat have come to the market, and these will undoubtedly admit of higher farming than the comparatively weak-strawed kinds. Consequently in manuring such kinds as Yeoman, Fenman, Swedish Iron, or Brookers' Double Standup, one may venture to give rather more generous treatment than has often been suggested in the past.

In general it may be said that if from one's knowledge of the land a smaller yield than 32 bushels per acre may be expected without manure, then manure of some kind should be applied. This is especially the case with heavy and medium soils, but wet, undrained, waterlogged land, or very light, sandy land, cannot be expected to give good crops of wheat, no matter what manure is applied, and the application of manure to such land will, in most cases, only result in disappointment.

Where more than 32 bushels per acre, say 36 to 40 bushels, may be expected, it is rather more difficult to say whether it is desirable to apply manure or not, and much will depend on the strength of straw of the variety of wheat to be grown.

Soil also has a considerable influence, and there are certain types of brick earth, that produce large heads and stiff straw, upon which it may be quite safe to push production to a high level. On the other hand, certain soils appear to contain some factor which limits the yield of grain, even though there is plenty of straw. A safe rule to follow is to manure up to the point at which a further application would cause the crop to lie down in an average season.

Where a second corn crop is being taken, say wheat after wheat or wheat after oats or barley, it will almost always be desirable to apply manure.

Farmyard manure at the rate of ten to fifteen loads per acre is an excellent manure for wheat, but artificial manures also give very good results. Soils containing plenty of lime might receive about 3 cwt. of superphosphate per acre, applied either at the time of sowing the wheat or in February—preferably at the time of sowing. If the soil is poor in lime, basic slag, bone flour, basic superphosphate, or some neutral phosphate should be used as a source of phosphate, and such manures should be applied in autumn. On heavy soils, 4 to 5 cwt. of highly citric soluble basic slag will often give as good results as superphosphate.

Potash manures are not usually required for wheat except on light or peaty land, where 2 cwt. of Kainit, or its equivalent of some other potash manure, may be used.

After a dressing of phosphates it will usually be desirable to apply some nitrogenous manure. For this purpose $\frac{3}{4}$ to $1\frac{1}{2}$ cwt. of sulphate of ammonia may be used on land containing plenty of lime. It is sometimes recommended that part of the sulphate of ammonia be applied in the autumn, but whether it is better to do this or to reserve the whole dressing until February really depends upon the season.

At Rothamsted it was found that in years of high winter rainfall spring applications gave considerably better results than autumn dressings, whilst in years of low winter rainfall there was very little difference. Taking an average of sixty-one years, the crop obtained by autumn application was 29·9 bushels, whereas, when the same quantity of ammonia was applied in spring, 32·1 bushels were obtained. On the other hand, in tests made by the Armstrong College in season 1915–6, at five out of seven centres, autumn and winter applications proved better than spring applications.

From the evidence that is available it would seem that the sulphate of ammonia should be applied as soon after the middle of February as the land is fit to walk on—provided there is not a hard frost, but applications as late as the month of April may have a very marked effect.

Nitrate of soda and nitrate of lime, applied at the rate of 1 to 2 cwt. per acre are also excellent sources of nitrogen for wheat, and are to be preferred to sulphate of ammonia on all soils poor in lime, and, as a general rule, in the drier districts of England. The relative prices per unit of nitrogen in the three manures may often be the deciding factor as to which of them to use.

At Rothamsted, on the basis of equal nitrogen content, nitrate of soda has given a better result than sulphate of ammonia. On the other hand, there are certain soils in the Midlands of England where nitrate of soda has a very decided adverse effect on the surface of the soil, and where, as a consequence, sulphate of ammonia is to be preferred.

Both nitrate of soda and nitrate of lime may be used with safety later in the season than sulphate of ammonia, as they are more quickly available to the plant. Nitrate of lime absorbs moisture from the air and dissolves in this moisture, so that even though a drought follows its application, the crop changes colour, becomes a dark green, and undoubtedly benefits. On the whole, early in April is the best time to apply these two manures, but in a late season even the middle of May may not be too late to obtain great benefit from their application. Nitrate of lime contains rather less nitrogen than nitrate of soda, so that a slightly heavier dressing of it is required than of the latter manure.

Where artificial manures are used for wheat it is, on most soils, desirable to use both phosphatic and nitrogenous manures. It is true that nitrogenous manures are often used alone, but it is sounder practice, and in the end likely to give better results, to apply both plant foods to the crop. The heavier classes of soils suffer more from the absence of phosphates than do lighter soils. Where, however, a field of wheat looks yellow in the spring, especially after a wet winter, a dressing of nitrogenous manure should be applied, even although no phosphates were applied in the autumn.

It may also often be highly desirable to apply a top dressing of some nitrogenous manure in spring when the crop is suffering from the attack of some pest such as wireworm. Where this is the case a dressing of nitrate of soda or nitrate of lime may often save the crop.

The practice of manuring wheat through the preceding leguminous crop has already been referred to, and it appears to be a thoroughly sound one, especially from a financial point of view. By means of a comparatively small expenditure on mineral manures—phosphates, or potash, or both—a considerable quantity of nitrogen may be accumulated by the leguminous crop and be available for the wheat crop. As a rule, on heavy land a dressing of 4 cwt. of 30 per cent superphosphate, or 4 to 7 cwt. of 30 per cent basic slag or its equivalent of other qualities, applied to the beans, peas, clover, or other leguminous crop preceding the wheat, will give good results, both on the leguminous crop and on the wheat following.

On lighter land a somewhat smaller quantity of phosphatic manure may be used, but a little potash, $\frac{3}{4}$ to 1 cwt. of muriate of potash, 3 to 4 cwt. of Kainit, or the equivalent in some other potash manure, would be a desirable addition to the phosphates applied to the leguminous crop.

When such manures have been applied to the preceding leguminous crop it is generally unnecessary to give any further dressing, except perhaps a little nitrogen in a quick-acting form.

Acreage under Wheat and Average Yields obtained

England and Wales.—A study of the statistics giving the area of wheat grown in the various parts of this country is of much interest. It is well known that the area under wheat is much less than it was in the seventies, and the extent of the shrinkage is evident from the figures given below.

The years 1914 and 1918 have been taken with the object of illustrating the effect of the Great War in increasing the area under wheat.

Table showing the Acreage and Yield per Acre of Wheat in England and Wales in the undermentioned Years

Year.	England.		Wales.	
	Acreage.	Average Yield per Acre.	Acreage.	Average Yield per Acre.
	Acres.	Bushels.	Acres.	Bushels.
1866	3,126,431	*	113,862	*
1870	3,247,973	*	126,928	*
1880	2,745,733	*	89,729	*
1890	2,255,694	30·79	68,669	24·94
1900	1,744,556	28·39	51,654	25·79
1910	1,716,629	30·19	39,428	27·59
1914	1,770,470	32·43	37,028	28·32
1918	2,460,695	33·10	95,966	29·70
1919	2,150,281	28·80	70,914	28·00
1920	1,824,037	28·60	50,548	24·30

* Produce statistics were not collected prior to 1885.

The following averages are also of interest to compare with the area in 1920.

Average of 1867–71	....	3,824,000 acres.
,, 1915–19	....	2,330,000 ,,
,, 1920	....	1,874,000 ,,

Examining these figures, the gradual fall in the area of wheat from the large acreage of fifty years ago is of much interest. In the year 1904 the area of wheat in the United Kingdom was 1,406,109 acres. This is the lowest acreage returned since 1866, the first year in which agricultural statistics were collected. After that year wheat-growing became slightly more profitable, and there was a gradual but small increase in the area under that crop.

During the War a strenuous effort was made to increase the area of wheat, and a substantial addition to the acreage resulted. That this result should have been achieved in spite of great scarcity of labour and of many other difficulties is testimony to the patriotism and energy of our farmers.

In 1919 the area had already fallen substantially in spite of the fact that a large area of wheat must have been sown on 11th November, 1918, when the armistice was declared, and for the 1920 harvest the fall was still more marked.

Examining the area in individual counties, and taking the year 1918

as showing the capacity for wheat-growing under strenuous war conditions, we find that the largest area of wheat in any individual county was in Lincolnshire with 224,117 acres. Yorkshire was second with more than 200,000 acres, whilst Essex, Norfolk, and Suffolk had more than 100,000 acres each. Cambridgeshire, Hertfordshire, Kent, Hampshire, Gloucester, Wiltshire, and Devonshire all had more than 60,000 acres.

It is in the eastern, midland, and southern counties of England, speaking generally, that the largest proportion of wheat to the total area of the county is grown.

In the *Agricultural Statistics* for 1920, published by the Ministry of Agriculture and Fisheries, the methods adopted in estimating the production of crops are explained. Estimates are obtained from local reporters of the average yield for each parish. Every effort is made, by employing experienced reporters, to make the statistics as accurate as possible.

Probably the chief use of such estimates of production is to show the variation from year to year, and the extent to which the home-grown produce contributes to the total supply. Similar figures are collected in other countries and they indicate the world's probable supply, and, for grain especially, they are of immense use in showing the international position as regards food-stuffs. It is also extremely interesting to compare the average yields obtained per acre year by year. The fluctuations are largely due to seasonal influences, but when larger periods are taken, say averages of a number of years, it seems likely that some indication may be obtained of changes due to causes other than the weather. With this object in view the yields of wheat in England and Wales have been worked out in averages of fifteen years since 1885.

Years.		Average Yield in Bushels per Acre.
1885–99	....	29·83
1890–1904	....	29·86
1895–1909	....	31·27
1900–14	....	31·22
1905–19	....	31·43

There is some slight evidence of a higher yield in the later years, which may be due to the increased attention which has been given recently to improved varieties of wheat, and to manuring. The averages of the two periods 1885-99 and 1890-1904 are, however, affected by the small yields obtained in 1886, 1892, 1893, and 1895, so that it is not safe to say with certainty that the rather larger yields obtained in the later years are due to improved methods of cultivation.

Scotland.—The following statement shows the area under wheat and the yield per acre in Scotland in the following years:

Year.	Area under Wheat.	Yield per Acre.
	Acres.	Bushels.
1860	Figures not available.	Figures not available.
1870	125,642	"
1880	73,976	"
1890	61,973	35·49
1900	48,832	36·43
1910	52,797	37·10
1914	60,521	42·31
1918	79,062	40·6

The county in Scotland which had the largest area of wheat, both in 1914 and 1918, was Fife with 12,669 and 15,113 acres respectively.

It will be noted that the average yield per acre in Scotland is higher than in England or Wales, but that the total area grown is comparatively small, quite a number of English counties growing as large an area as is found in the whole of Scotland. Doubtless the higher yield is due partly to the fact that in Scotland wheat is only grown in favourable situations, whereas in England it is one of the principal crops, and is grown under all sorts of conditions, favourable and otherwise. Further, in England and Wales about 7 per cent of the total cultivated area is devoted to wheat, whereas in Scotland only $1\frac{1}{2}$ per cent of that area is sown with our principal cereal. Apart from this, however, it is probable that the Scottish farmer in the good tillage districts uses more artificial manure than his English brother, and the larger yield per acre obtained may be due partly to this cause.

Ireland.—The following table gives the area under wheat in Ireland, and the estimated yield per statute acre.

Year.	Area under Wheat.	Estimated Yield per Statute Acre.
	Acres.	Bushels.
1860	466,415	20·3
1870	259,846	21·6
1880	148,708	26·5
1890	92,341	27·1
1900	53,821	29·5
1910	47,631	34·2
1914	36,913	36·2
1918	157,326	34·3

The county of Cork has the largest area of wheat of any county in Ireland

in both 1914 and 1918, the figures being 7033 and 23,869 acres respectively. Counties Wexford, Down, and Galway all had over 10,000 acres in 1918.

The foregoing figures show in the most striking way the great shrinkage in area of wheat in Ireland during the agricultural depression, and the rapid increase after 1914 owing to war conditions. They also afford evidence of the very considerable capacity for growing wheat possessed by the Emerald Isle. The very much larger yields of wheat per acre obtained in the later years, when compared with 1860, are hardly likely to be due to seasonal influences. In 1860, in all probability, much second-class land was sown with wheat, whereas, recently, with the restricted area grown, most of the land sown with wheat would be fairly well suited for that purpose. There is, however, very little doubt that the better yields obtained of late years are in great measure due to improved methods of tillage and manuring.

Comparison of British Area and Average Yield of Wheat with that in other Countries

The average yield of wheat in the United Kingdom for the five years preceding 1919 is given as 31·6 bushels per acre, that for 1919 being 29·2 bushels. Comparing this with yields obtained in other countries we find that the only countries which in 1919 exceeded the British yield are Denmark with 47·5 bushels, the Netherlands with 37·2 bushels, and Belgium with 30·1 bushels. The average for the years 1915 to 1918 in Denmark was 40·8 bushels, and in the Netherlands, for the five nearest years to 1919 available, 36·8 bushels. Switzerland and Sweden both had 27 bushels per acre in 1919, whilst Norway had 26·1, and Germany 24·9 bushels.

It is worthy of note, and somewhat comforting to the amour-propre of the Britisher, that the three countries which had a higher yield than the United Kingdom all grow small acreages of wheat, Denmark having only 124,488 acres in 1919, less than many English counties; the Netherlands, 161,839 acres; and Belgium, 328,426 acres.

It is also worthy of note that all these three countries have a much larger acreage of rye than wheat; in fact, Denmark has more than 500,000 acres of that cereal, and one may reasonably conclude that these countries grow rye on their inferior land and wheat only on their best land, whereas, especially in England, we grow very little rye and consequently grow wheat on all classes of land.

Except during recent years, when, under war pressure, more land was put under wheat, the area usually devoted to the wheat crop in

Denmark has not exceeded $1\frac{1}{2}$ per cent of the total cultivated area as compared with 7 per cent in England and Wales. In all probability another reason why Denmark has so much higher an average yield is that in that country they use much more artificial manure for wheat than we do, and undoubtedly our average might be greatly, and, in the majority of cases, also profitably, increased by a larger use of artificial manure.

The average yields of wheat in Holland appear to show an appreciable increase of late years. In the thirty years preceding 1900, some tendency to increase was observable, the average yields rising from about 24 to 27 bushels per acre. In the thirty-five years from 1885 to 1919 a decided increase has been apparent. The averages in fifteen-year periods show a practically continuous increase from $27\frac{1}{2}$ bushels in 1885–99, to nearly $35\frac{1}{2}$ bushels in 1905–19. The yield per acre in Holland, therefore, now materially exceeds that of England and Wales, but this again is largely due to the relatively smaller acreage under wheat in Holland, as it represents less than 3 per cent of the cultivated area. There was a considerable reduction in the wheat area in Holland in the years previous to 1900, and probably the land which remained under wheat would be the best suited for the crop. Since 1900, however, there has not been very much change in the wheat area in that country, so that any increase in production per acre since then must be due to other causes. The yields of barley and oats in Holland also show a tendency to increase.

Of the European countries France, with an area of more than 11 million acres, has an average yield of about 16 bushels per acre; Italy also, with 11 million acres, has also an average of 16 bushels per acre; Spain, with 10 million acres, has an average yield of 13 bushels; Germany (including territory ceded) had a little over 3 million acres in 1919, with an average yield of 24·9 bushels. It is interesting to note that in Germany, as in Denmark, rye occupies about three times the area of wheat. Roumania, with about 3 million acres in 1919, had an average yield of 16 bushels; Bulgaria, with 2 million acres, also yielded about 16 bushels per acre.

Of the other great wheat-growing countries of the world, the United States of America, with 73 million acres in 1919, had an average yield of 14·7 bushels. For the twenty-five years prior to 1890, the average yield was about 12 bushels per acre; but since then it has continually risen, and for the ten years ending in 1918 it was 14·87 bushels per acre. The Department of Agriculture states that the tendency towards enlarged output per acre is general throughout the United States, and is due principally to the practice of improved agricultural methods, which include, amongst other things, more intensive cultivation.

Of the other countries, European and Asiatic Russia in 1914 had about 80 million acres with a yield of about 10 bushels per acre, and India, with about 30 million acres, a yield of about 12 bushels. Canada

in 1919 had 19 million acres with a yield of 17 bushels per acre. The Argentine had 15 million acres with a yield of 14 bushels. Australia, from 1914 to 1917, had an average area of 10 million acres, the average yield being about 10 bushels per acre.

Varieties of Wheat

It is outside the scope of this article to deal with the question of the botanical characteristics of the various varieties of wheat, and it is proposed merely to discuss a few of the commoner British varieties from the practical point of view.

Most British varieties of wheat may be grouped under three heads:

1. **White Wheats.**—Grain white in colour.
2. **Red Wheats.**—Grain red or brown.
3. **Rivet, Cone, or Clog Wheats.**

The difference between white and red wheat is not well marked, and under certain cultural conditions a white wheat may produce grain more or less reddish in colour. Thus, when the writer first obtained a bushel of Swedish Iron wheat from Sweden in 1912 the grain was distinctly white, but since then the produce of that original supply has always been red.

Of late years much valuable work has been done in this country by various workers in the production of improved varieties of wheat. Professor R. H. Biffen, of the University of Cambridge, has for a number of years been raising varieties of wheat by cross breeding. Following upon the principles discovered by Gregor Mendel, he has endeavoured to combine in a new variety desirable points possessed by either of the parents, as, for example, a stiff straw with "strong" milling qualities.

Sir A. D. Hall, F.R.S., at the meeting of the British Association at Cardiff in 1920, paid a tribute to Professor Biffen's work. He estimates that on eastern county farms Professor Biffen's varieties have raised the average yield of wheat by at least 10 per cent. He also points out that the work of improvement will take many years of patient labour before the ideals of cropping power, strength of straw, resistance to disease, and milling qualities are attained.

For some years Professor Perceval, of the University College, Reading, has devoted much time to the collection and study of wheats from all parts of the world. Some fifteen hundred kinds have been obtained and grown each year at the University farm at Shinfield, Reading. Professor Perceval has made high yield per acre the basis of his selection; quality, however, has not been ignored, and great stress has

been laid upon the importance of stiff non-lodging straw as well as resistance to rust and other diseases. The wheats Professor Perceval has introduced are all selections, and represent the best of several hundreds which have been tested.

Valuable work in raising new varieties and selecting pure stocks of well-known kinds has also been done in Ireland, under the auspices of the Department of Agriculture. Pure selections of Queen Wilhelmina, White Standup, Squarehead's Master, and Red Fife have been made. In addition, several new forms of spring wheat, resulting from a cross between Red Fife and April Red, are being grown, as are also selections of Swedish Iron, Red Velvet, and Australian wheat.

A great deal of useful work has also been done by various seedsmen in introducing and selecting varieties, whilst farmers and other private individuals have helped in the work by selecting and raising up new stocks of various varieties.

Varieties of wheat have also been produced at the Swedish Plant-Breeding Station at Svalöf, Sweden. These have been introduced into this country, and one of them—Swedish Iron—has been remarkably successful in producing heavy crops. The following is a short description of a few of the more important wheats grown in this country. In the descriptions the quality of grain has been referred to in many cases, and, in order to avoid confusion, it should be noted that the word " good " has been used to describe the quality of such ordinary English wheats as Squarehead's Master and Little Joss. Professor Biffen, however, has very kindly pointed out to the writer that, considering the very high standard of quality of Canadian wheat, or Yeoman, ordinary English wheats really ought to be described as of " bad " quality. To describe them thus would, however, probably lead to misunderstanding, hence the word " good " has been used to indicate the quality of an English wheat —such, for example, as Squarehead's Master, which would be described as of " good quality " by an average miller.

WHITE WHEATS

Burgoyne's Fife.—A hybrid between Rough Chaff and Fife, with a short, fairly lax ear and white hairy chaff. The grain is small and white. This variety has proved very superior to Rough Chaff in quality, but not equal to English-grown Red Fife at its best. It has also proved rather disappointing in cropping capacity, hence is not much grown now. It is, however, a wheat of much interest from a scientific and historical point of view.

Benefactor.—A white wheat with white velvety chaff. The ear is short and somewhat bulgy. The grain is of very fair quality. This wheat was introduced by Messrs. Garton, of Warrington.

Brookers Double Standup.—A white wheat with white chaff and short straw. The grain has proved in East Suffolk trials to be of rather better quality than Wilhelmina and Victor, which varieties it closely resembles. Brookers has proved to be a very heavy yielder, giving the heaviest yield per acre in East Suffolk on a number of occasions. It has also been very successfully grown in South Nottinghamshire. It was first brought to the notice of the writer by Mr. David Black, of Bacton, Stowmarket, Suffolk. Mr. Black has now introduced a selection from Brookers with red grain and rather stronger straw.

Fenman.—A wheat with fairly compact ears and whitish and somewhat transparent grain of good milling quality. The straw is stiff and not very long, and the chaff is white. Fenman is a heavy cropper on good wheat land, but is not so well suited for poor land. It was introduced by Professor Biffen, of Cambridge, its parentage being somewhat complex. Rivet was crossed with Sunbrown, a fixed hybrid being obtained which was then crossed with a variety found in Red Fife. Fenman is often classed as a red variety.

Rough Chaff White.—A velvety chaffed wheat of poor milling quality.

Snowdrop.—A white wheat with short straw, introduced by Messrs. J. K. King & Sons.

Starling.—A white wheat introduced by Professor Perceval. It is dense-eared, with smooth white chaff. The straw is stout and of medium length.

Standup White.—A white wheat with white chaff, ear of medium length, and straw very short and stiff. The grain is of good milling quality. Several seedsmen, including Carters and Webbs, have selections of this variety catalogued. In field experiments conducted some years ago, this variety gave very good results and often secured first place. Of late years, however, more recently introduced varieties have given heavier crops.

Victor.—A white wheat with white chaff, very similar in appearance to Wilhelmina and Brookers. It is a very good cropper, and the quality of the grain is very similar to that of Wilhelmina. Victor was introduced by Messrs. Garton, of Warrington. Victor, Wilhelmina, and White Brookers are in many respects very similar in character.

Wilhelmina.—A white wheat with white chaff, and rather short straw. The grain is rather small, floury, and of fair quality. Wilhelmina is a very heavy yielder, but it usually produces a large quantity of small corn. It was introduced to this country from Holland, and on the whole is one of the most valuable of the white wheats.

White Queen.—A white wheat with white chaff, ear of medium length; straw also medium in length, and stiff. The grain is of good milling quality. Introduced by Messrs. Webb.

RED WHEATS

April Bearded Wheat.—The ears of this variety are fairly long and lax. The chaff is red and the grain small, red, clear, flinty, and of good quality. This variety may be sown later in spring than any other kind of wheat commonly grown in this country. Even if not sown till early in April it will often give quite a good crop. It is especially useful for filling up thin plants of an autumn-sown wheat. It is commonly sown for home use in the hill districts of Wales, and ripens satisfactorily at considerable elevations. The straw is rather weak, and on this account it should not be sown on land in high condition. On land in poor condition it may be relied upon to produce a fair crop.

Browick Grey Chaff.—An old variety of red wheat with grey chaff. The ears are short, square, and closely set. The straw is strong, and a heavy yield of grain per acre is usually obtained. This wheat is well known in the north of England and preferred to Squarehead's Master in some districts. As a rule it is a little later in ripening than that variety, but on suitable land gives a slightly heavier crop.

Essex Conqueror.—A red wheat with white chaff and rather long straw. This variety was introduced by Messrs. J. K. King & Sons, Essex.

Fox.—An uncommon type of wheat having beardless ears, with red, woolly chaff. The ears taper slightly towards the tip, but the spikelets are well filled with pale reddish grain of excellent milling quality. The straw is somewhat short, but the plants tiller well. Fox wheat is especially suited to warm, well-drained soils of a light or gravelly nature, and on these it gives a higher yield than most English varieties. One of Professor Perceval's wheats.

Golden Drop.—An old variety of red wheat which is very liable to rust.

Harvester.—A variety with red grain and white chaff, recently introduced by Messrs. Webb & Sons, Wordsley, Stourbridge.

John Bull.—A red wheat with white chaff. This variety was introduced by Messrs. J. K. King, and the straw is of moderate length.

Little Joss.—A red wheat with large grain of good milling quality. The straw is long, the chaff reddish in colour, and the ears somewhat thin. This variety possesses great tillering power, and is particularly well suited for light soils and for fen land, but where the land is very rich it is apt to become laid. It gives, however, very good yields on all soils not in too high a state of fertility. It is very popular in the eastern counties of England. This wheat was introduced by Professor R. H. Biffen and is the result of a cross, the parents being Squarehead's Master and Ghirka. It is comparatively immune to rust, and its heavy yielding powers are probably partly due to this.

Martin.—A red-chaffed, beardless variety with a dense square ear. The grain is red, plump, and of good quality. The plant is hardy and tillers well, and the straw stout and of medium height. This wheat is adapted for growth on the stronger class of soils. It is one of Professor Perceval's wheats.

Marshal Foch.—A red wheat with white chaff. The ear is rather short, and the straw of medium length. This wheat was produced by Messrs. Garton, of Warrington, by crossing "Regenerated" White Standup with "Regenerated" Browick, and has given good results in comparative trials.

Partridge.—A white-chaffed, beardless wheat with pale red grain. It tillers well, ripens somewhat earlier than most wheats, and is adapted to all ordinary wheat-land. It may be sown with success up to February. This variety was introduced by Professor Perceval.

Plover.—A fine Squarehead variety of wheat with smooth chaff, red grain, and stout straw of medium height. Introduced by Professor Perceval.

Red Standup.—A stiff-strawed variety with red grain; the grain is thin skinned and of good quality. This variety gave good results in trials conducted by Cheshire County Council. It was introduced by Messrs. James Carter & Co., Raynes Park, London.

Squarehead's Master.—A red wheat with red chaff, fairly long straw, and grain of good milling quality. Until recently this variety was probably more widely grown in the British Isles than any other kind. Of late years, however, several new varieties have been found which give a heavier yield per acre when grown under exactly similar conditions, and consequently farmers have considerably reduced their area of this variety.

Standard Red.—A red wheat, with red chaff, long or medium ear, and fairly long straw. The grain is of good milling quality. As a cropper it is probably about equal to Squarehead's Master, which variety it very strongly resembles. This wheat was introduced by Messrs. E. Webb and Sons, of Wordsley, Stourbridge, and is a useful wheat on average land.

Swan.—A white-chaffed, beardless variety with moderately dense ears which are well filled from top to bottom. It succeeds best on loams. The straw is stout and fairly tall. The grain is of good quality, plump, and pale red. This variety was introduced by Professor Perceval.

Swedish (Svalöf) Iron.—A red wheat with white chaff and strong straw of good length. This variety was introduced from the Swedish Plant Breeding Station, Svalöf, Sweden. It produces a very heavy yield of grain; in fact, in many experiments in this country it has given the heaviest yield of all varieties tested. Unfortunately the quality of the grain is not good from a miller's point of view, and this may be a serious defect

in the future, although during the war, when heavy yield was so important, it mattered very little and made no difference in price. During the autumn and winter this wheat usually looks weakly and thin on the ground, but it makes rapid growth during May. Swedish Iron II is a new strain of Swedish Iron, but it has not yet been sufficiently tried in this country.

Swedish (Svalöf) Extra Squarehead II.—A red wheat with white chaff and very stiff straw. This variety is one of the stiffest strawed wheats grown in this country. Unfortunately this wheat is very subject to rust and the quality of the grain is not good. In some years it yields well, but on the whole it is inferior in yielding capacity to Swedish Iron.

Stormproof.—A red wheat with stiff straw and white chaff. The head is square in shape. It ripens somewhat late. This variety was introduced by Messrs. James Carter & Co.

The Hawk.—A red wheat, bearded, ear fairly long, and straw strong and stiff. This wheat is claimed to be protected from birds by the beards. It was produced by Messrs. Garton, of Warrington, as the result of a cross between Browick and Herrison Bearded. It ripens rather late, and is somewhat difficult to thresh.

Universal.—Another variety with red grain and white chaff, introduced by Messrs. Webb.

White-chaffed Red Squarehead.—An old but very useful variety of wheat. It produces a bold square head and is an excellent cropper. This variety is very similar to Browick. The quality of the grain is fair, but not quite so good as that of Squarehead's Master.

Yeoman.—A red wheat with rather long grain of extremely good milling quality. The straw is very stiff and short, and the chaff is white. This wheat is remarkable for the high quality of its grain, and the stiffness of its straw. It is well suited for intensive cultivation, especially on land in a very high state of fertility, and has produced the almost record crop of 96 bushels per acre. On poor land, especially poor light land, it is not very successful. Yeoman was introduced by Professor Biffen, the parents being Browick and Red Fife. It is probably the only heavy-yielding wheat grown in England of a quality similar to Canadian Red Fife. In 1921—a very dry year—it gave good results in comparative trials.

In addition to the foregoing varieties, the following Canadian and French red wheats are of interest in this country.

Canadian Wheats.

Marquis.—This is a wheat which has proved extraordinarily successful in North America. It was bred by Dr. A. P. Saunders in 1892, and reselected in 1903 by Dr. Charles E. Saunders. After that date its success was phenomenal, and its spread over the North American continent must be regarded as one of the romances of modern wheat growing.

It is estimated that in 1918 300 million bushels of this variety were produced.

Red Fife and allied types.—Red Fife is a famous wheat grown in Canada. It originated in Central Europe, probably in Galicia, and is remarkable for its "strength". Unfortunately, when grown in this country, it does not produce a large enough crop to make its cultivation remunerative. Red Fife wheat has, however, proved very useful to wheat breeders in this country, and has been fully investigated by the Home-grown Wheat Committee of the National Association of British and Irish Millers. It has acted as the "strong" parent in crosses made with the object of combining strength with cropping power.

Wheats of the Red Fife type have short, lean, lax ears and pale coloured chaffs, with small red grains. The wheat is clear and flinty in appearance, and is possessed of extraordinary strength. Similar in many ways to Red Fife are White Fife, Cook's Wonder, and New Augustine.

French Wheats.

Dreadnought (French name *Hâtif Inversable*).—A strong-strawed variety of French wheat suitable for spring sowing. It gave very good results in trials conducted with spring wheat in Essex in 1911 and 1913, being superior to Red Marvel in both these years. In 1912, however, Red Marvel gave a higher yield.

Red Marvel (French name *Japhet*).—The variety has red grain of large size and not very good milling quality. The straw is long and weaker than that of Dreadnought. The ear is rather long and open, and the grain is somewhat liable to "smut". It may be sown in spring as well as autumn, and when this is done a crop is often obtained comparable in weight to an autumn-sown variety. It may generally be depended upon to yield a satisfactory crop when sown up to the end of March, although February sowing is preferable.

Red Admiral is a variety closely akin to Red Marvel, while White Marvel also resembles the red variety except that it is white.

Sensation (*Bon Fermier*).—A French wheat with red grain and white chaff. The straw is short and stiff. In the Essex trials of spring wheat in 1911, and in trials in Hertfordshire in the same year, it gave a smaller yield than Red Marvel and Dreadnought.

RIVET WHEATS

Perceval's Blue Cone is a selection of Rivet wheat made by Professor Perceval. It can only be grown satisfactorily on well-drained soils, and is suited best to the southern half of England. It possesses very narrow young leaves and shoots which during the winter and spring

lie close to the ground. It often looks disappointing in February, but makes very rapid growth later on.

Rivet or Cone Wheat (*Triticum turgidum*).—A bearded red wheat with very long straw. It belongs to a different botanical family from other English wheats.

Rivet wheat is called " English wheat " on the Continent, and although it is not very extensively grown in England, it has been cultivated in this country for a very long time, and is, in fact, one of the oldest kinds known. It is suitable for stiff heavy land, on which it gives good yields of grain of poor milling quality. Rivet wheat should be sown early, viz. by the end of September or early in October. It ripens about a week later than most varieties of wheat. The strong awns render it more or less immune to attack by birds.

Comparative Yields of different Varieties of Wheat

Field experiments have been conducted by the various agricultural colleges and county councils in this country to test the relative yields of the new varieties of wheat, compared with older and better-known kinds. These experiments have been by no means so numerous as the importance of the wheat crop would justify; and, considering the enormous annual value of the wheat grown in this country, it is much to be regretted that the question of what is the best variety to grow in any particular locality has not been more fully investigated.

In a lecture delivered in the autumn of 1920, Principal P. Hedworth Foulkes, of the Harper Adams Agricultural College, gave it as his opinion that the higher yield of wheat obtained during the years 1915–9 in England and Wales, as compared with that in 1867–71, must be attributed to the recent introduction of improved varieties. In the writer's opinion the spread of improved varieties would have been much more rapid had each county conducted two or three tests annually and published the results in the local press. The cost of these tests need not have exceeded £30 per county, i.e. a total sum of about £1500 annually for England and Wales. It is extremely likely that this work would have resulted in an increased yield of at least 1 bushel per acre over our entire acreage—roughly 2,000,000 bushels, worth about a million pounds annually. Moreover, this extra wheat would have been available at a time when wheat was our greatest national need.

The value of a scheme of experimental work of this kind would be greater if it were arranged for groups of counties to test the same varieties. Averages would then be available which would be more reliable

than the results from the small number of tests which can be conducted in a single county.

The following is a summary of the results of some of the experimental work available, but readers desiring details of the various tests are recommended to study the reports published by the various colleges or county councils referred to.

Trials conducted by the East Anglian Institute of Agriculture in Essex show that over an average of years Little Joss and Victor gave practically the same yield, Wilhelmina 1 bushel less, while Squarehead's Master and Browick were 4 bushels behind Little Joss.

Varieties of wheat for spring sowing were also tested in 1911, 1912, and 1913 by the East Anglian Institute of Agriculture in Essex and Hertfordshire, with the following results:

Name of Variety.	Centres, 1911.		Centres, 1912.		Centre, 1913.
	Essex, sown Feb. 23.	Herts, sown Feb. 15.	Essex, sown March 27.	Herts, sown March 28.	Essex, sown March 11.
Dreadnought	58	42½	30½	—	41
Red Marvel	53	—	30	41½	35½
Red Admiral	—	45	—	—	—
Squarehead's Master..	52	41½	11	failure	38
Burgoyne's Fife ..	51	28½	28	34	35½
Sensation	47½	40	—	—	—

The University of Leeds has conducted tests with wheat for a number of years. The results for the years 1916 to 1920 inclusive gave the following averages, in bushels per acre, for the varieties tested: Iron, 44¼; Standard Red, 43; Victor and Fenman, 42¼; Squarehead's Master and Little Joss, 42; Benefactor, 41¼; Browick, 41; White Standard, 39¼. Stormproof, a variety tested in 1920 only, was second in point of yield, but gave grain of superior quality.

In 1921 trials were conducted at Garforth and on a farm near Northallerton (Appleton Wiske).

At Garforth the heaviest yield was given by Tystofte-Smaalvede, with 58½ bushels per acre. This yield is not, however, strictly comparable with the other figures, as the seed was once grown locally, whereas all the other varieties were grown from new seed. Of other kinds Standard Red gave 56¾ bushels, Victor 55 bushels, Squarehead's Master 53½ bushels, Marshal Foch 53 bushels, Little Joss 52¼, Iron II 51½. The lowest yield was given by The Hawk, with 47¾ bushels.

At Appleton Wiske Victor gave 55⅓ bushels, Iron II 54⅔ bushels, Yeoman 52⅓ bushels, Squarehead's Master 40⅓ bushels, Creeping Red 44 bushels, and Benefactor 42⅓.

In East Suffolk, trials have been conducted for ten years, results

being available from twenty-four individual centres during that period. Squarehead's Master was taken as the standard variety with which to compare the other varieties tested. Swedish Iron, Brookers Double Standup, Victor, Wilhelmina, Little Joss, and Fenman on an average all gave superior yields to Squarehead's Master, and proved of outstanding merit as far as cropping qualities were concerned. Taking the average of the results in 1920 from three centres, Swedish Iron gave 50½ bushels per acre, Red Brookers and Marshal Foch 45½ bushels, Fenman 44¾ bushels, Squarehead's Master 41¼ bushels; Yeoman tested at two centres gave a much heavier yield than Squarehead's Master at both these centres, but not so high a yield as Swedish Iron. Little Joss at two centres also proved superior to Squarehead's Master, and Yeoman yielded more heavily than Little Joss. In 1921, Yeoman and Swedish Iron both gave very good yields. Taking an average of three centres, Yeoman gave 55 bushels 3 stones, Swedish Iron II 54 bushels, Marshal Foch 53 bushels 3 stones, Wilhelmina 50 bushels 4 stones, Squarehead's Master 49 bushels 2 stones. Swedish Iron was only included at two centres. It gave a better yield than Yeoman at one centre and not so good at another.

In the Herefordshire trials of 1915, 1916, and 1917, the striking feature in the results was the superiority of the white wheats, Victor, Standup White, and Snowdrop, as on an average of these three years Snowdrop White gave 43 bushels per acre, Victor 42, Standup White 40¼, Squarehead's Master 39¼, Benefactor 38¾, Little Joss 38, Browick 37¾, Standup Red 37¼. In 1918 Standard Red gave the highest yield, with 41¾ bushels per acre, Snowdrop White 39¾, Yeoman 39¼.

A variety test with spring wheats was also conducted in 1918 in Herefordshire, the seed being sown on 3rd April. April Bearded with 35¼ bushels and New Augustine (32 bushels) proved the highest yielders of eight kinds. Red Marvel gave only 23 bushels per acre.

At the Harper Adams Agricultural College, trials were conducted with winter wheat during the years 1917, 1918, and 1919, the following being the average yields obtained: Svalöf, or Swedish Iron, 56 bushels per acre; Fenman, 52; Marshal Foch, 51½; Fox, 51; Victor, 49½; Browick, 49½; Yeoman, 48; Squarehead's Master, 42.

Marvel gave the heaviest crop amongst four kinds of spring wheats tested, but April Bearded was not included in these trials.

At the South-Eastern Agricultural College, Wye, trials have been conducted at intervals. In 1905 White Standup, and in 1906 Essex Conqueror, gave the highest yields. Victor obtained premier position in 1911. In 1912 Blue Cone gave a heavier yield than Victor; in 1913 Wilhelmina was first on the list and Victor second. In 1919 Yeoman gave 47½ bushels of grain per acre, and was followed by The Hawk with 47 bushels, Benefactor with 45 bushels, and Browick with 44 bushels. In 1920, Yeoman

again gave the highest yield with $60\frac{5}{8}$ bushels, followed by Victor with $59\frac{1}{4}$ bushels, and Swedish Iron with 54 bushels. Of the varieties tested Yeoman stood up best and was of much the best quality.

In Northamptonshire a trial with varieties of wheat was carried out in 1914. The highest yields were obtained from Little Joss with $34\frac{1}{2}$ bushels, Squarehead's Master with $34\frac{1}{4}$ bushels, and Essex Conqueror with $33\frac{3}{4}$ bushels.

The University College of North Wales, Bangor, conducted experiments with varieties of wheat in 1915 at the College Farm on plots which were in duplicate. Taking the average yield, Victor gave $51\frac{3}{4}$ bushels per acre, Benefactor $47\frac{3}{4}$ bushels, Extra Squarehead 46 bushels, Little Joss 42 bushels, and Cone 40 bushels. Trials were also conducted with spring wheat when the varieties Dreadnought and Red Marvel were tested, and gave exactly the same yield—40 bushels per acre.

The University College, Reading, in conjunction with the Berkshire Agricultural Instruction Committee, conducted trials with varieties of wheat in 1915, 1916, and 1917 at eleven centres. Several of the varieties introduced by Professor Perceval were grown for comparison with Little Joss. Three varieties were tested at all the centres, and of these Swan gave on the average a slightly higher yield than Little Joss, Martin gave about the same as Little Joss, and Badger a rather smaller yield.

At the Midland Agricultural and Dairy College, Kingston, Derby, varieties of wheat have been tested on heavy and light soils for several years. On the heavy soil on an average of three years, Swedish Iron gave 47 bushels per acre, Benefactor 41 bushels, Wilhelmina 39 bushels, Browick $38\frac{1}{2}$ bushels, Sun 38 bushels, Swedish Extra Squarehead II 38 bushels, Squarehead's Master 32 bushels.

On the light soil, Iron wheat again gave the heaviest yield with 40 bushels per acre, and was followed by Sun with 38 bushels, Wilhelmina with 37 bushels, Little Joss with 32 bushels, and Squarehead's Master with $29\frac{1}{2}$ bushels.

At another centre, on clay loam, Swedish Iron gave 48 bushels, Fenman 43 bushels, and Yeoman 42 bushels. The best standing varieties were stated to be Iron, Sun, Extra Squarehead II, Wilhelmina, and Benefactor; and Yeoman was placed first as regards quality.

In Devonshire, Little Joss gave the heaviest yield of four varieties tested in 1913, but in the following year Victor, Snowdrop, and Squarehead's Master gave heavier yields than Little Joss.

At Warwickshire Farm Institute Yeoman and Swedish Iron were compared for three years. Swedish Iron gave an average yield of $48\frac{1}{2}$ bushels and Yeoman $45\frac{1}{2}$ bushels.

At Cockle Park, in Northumberland, in a test in 1919, Yeoman gave $67\frac{1}{2}$ bushels, Benefactor $66\frac{1}{2}$ bushels, and Iron 59 bushels.

In Shropshire in 1921 four varieties were tested on four farms, and

the following average yields obtained: Victor, 43½ bushels; Fenman, 42 bushels; Yeoman, 40¾ bushels; Iron, 36¼ bushels.

Edinburgh and East of Scotland College of Agriculture conducted trials with varieties of wheat at three centres in 1908-9. Browick gave 69 bushels per acre, White Chaff Squarehead 65¾ bushels, Carters Standup White 62¼, and Webb's Standard Red 60¾ bushels. Taking into account quality as well as yield, the most profitable varieties were White Chaff Squarehead and Carters White Standup. Browick proved of the lowest quality of the varieties tested.

Several experiments have been conducted in Ireland under the auspices of the Irish Department of Agriculture, and in 1919, at the Albert Agricultural College, Glasnevin, Dublin, nine varieties were tested. Yeoman gave 37 cwt. 7 st. per statute acre, Hawk 37 cwt. 6 st., Red Velvet 34 cwt. 1 st., Wilhelmina 33 cwt. 6 st., White Standup 33 cwt. 6 st., Squarehead's Master 32 cwt. 5 st., and Cone 29 cwt.

In 1920 variety tests with autumn-sown wheats were carried out at twenty-three centres in sixteen counties in Ireland. The average yields per statute acre, as well as the corresponding figures for two of the varieties for the previous year, are given in the following table:

Variety.	Average Yield per Statute Acre, 1920. 23 Centres.			Average Yield per Statute Acre, 1919. 40 Centres.		
	Grain.		Straw.	Grain.		Straw.
	Cwt.	Qr.	Cwt.	Cwt.	Qr.	Cwt.
Queen Wilhelmina ..	21	1	38	25	1	40
Yeoman	20	2	37	—		—
Squarehead's Master ..	20	0	39	24	2	40
Fenman	19	2	39	—		—

At Rothamsted Experimental Station, between the years 1871 and 1881, trials were made with a number of varieties of wheat. In these tests five wheats stand out as considerably heavier croppers than the others: Rivet, White Chaff Red, Club, Golden Drop, and Boles Prolific. Most of the kinds then tested are now very little grown, but Sir A. D. Hall and Dr. Russell, in the book of the Rothamsted Experiments, point out that Rivet is perhaps the oldest English wheat remaining in cultivation. It is known everywhere for its heavy yields on strong land, its coarse straw, the inferior quality of its grain, and its bearded character.

In selecting a variety, growers of wheat are strongly recommended to closely follow the results of local trials. It is evident, however, from the results of the tests given that, on good wheat soil, Swedish Iron is a very good cropping variety, but unfortunately its quality leaves much

to be desired, and in the future it is quite possible that this failing may prove a very serious defect from the point of view of the farmer who wishes to grow the wheat which will give him, not merely the largest yield, but the largest money return per acre. In the past, however, it has often happened that the heaviest yielding wheat has been the most profitable to grow.

Growers of wheat on good land, who wish to select a variety of high-milling quality and also a heavy cropper, may with confidence be recommended to try Yeoman. That variety possesses many valuable qualities. It is of splendid milling quality, has a stiff straw and very good tillering capacity, whilst in certain seasons it appears equal to Swedish Iron in cropping power. It is not, however, suitable for poor land. Fenman is also a good wheat on good land.

For growing under ordinary conditions the white wheats Victor, Wilhelmina, and Brookers Double Standup may be relied upon to give good yields of average quality grain. A defect of these wheats is that they are easily damaged in a wet harvest; they are, however, excellent wheats for ordinary conditions.

Little Joss and Browick, amongst red wheats, are also very useful for land of average fertility, and they both as a rule give a better yield than Squarehead's Master. Little Joss is also very suitable for light land, and is probably the best wheat for such land.

Although Squarehead's Master is such a general favourite, a careful examination of the results of field experiments leads one quite definitely to the conclusion that it is inferior in yield to the extent of several bushels per acre when compared with some of the newer kinds, more especially when it is grown on good soils.

Quality in Wheat

Quality in wheat depends upon a number of factors. The work of the Home-grown Wheat Committee has brought before the British farmer the importance of quality in home-grown wheat. Mr. A. E. Humphries, in a paper read before the British Association in Winnipeg in August, 1909, on " Quality in Wheaten Flour ", summarized the varied factors which contribute to quality in wheat. He pointed out that strength, colour, and flavour have been regarded as the points of importance. The term " strength ", however, frequently includes (*a*) stability, i.e. the facility with which large masses of dough can be handled in the bakehouse; (*b*) the capacity for making a large quantity of bread from a given weight of flour; (*c*) the size and shape of loaf. He himself defined strength as " the capacity for making large, shapely, and therefore well-aerated loaves ". Mr. Humphries also pointed out that opinions differ as to

whether perfection of colour implies whiteness of chalky or creamy hue in the flour, but that all are agreed it should imply brightness of appearance in crumb and crust.

Dr. Charles Saunders[1] summarized the various factors contributing to quality in wheat, and more recently Professor C. H. Bailey[2] has also dealt with the same subject. Professor Bailey, who is a cereal technologist, regards the following points as of importance:

1. Relative plumpness of the kernels, which influences the yield and percentage of flour which can be produced from the grain.

2. Density of the kernels. This also affects the yield of flour, since, other things being equal, a larger proportion of the " floury " portion of the kernel can be separated as flour when it is hard or vitreous in texture, than when soft or starchy.

3. Moisture content of grain. This affects its keeping quality, the ease in milling, and the losses which occur owing to evaporation during the processes of milling.

4. Soundness of the grain, as indicating its freedom from fermentive changes.

5. Baking strength of the flour, or its ability to produce large well-raised loaves of bread. The relative strength of flour is influenced by at least two groups of factors: (*a*) the percentage and physical properties of the two principal proteins of wheat flour known collectively as gluten; and (*b*) the quantity and nature of the yeast food originally present in the flour and formed during the process of fermentation.

6. Absorption, or percentage of water necessary to make a dough of proper consistency from the flour in bread-making, since the more water that can be employed per unit of flour, the greater the weight of bread which can be produced from it.

7. The colour of the flour, the demand being for a very white product.

In the uncertain climate of the United Kingdom, the quality of the wheat placed upon the market depends to a considerable extent upon the weather during harvest. In a wet harvest British-grown grain has almost always a high moisture content, and may be weathered or slightly mouldy. A certain proportion of the grains may have grown or germinated before cutting or when standing in the stack. It frequently happens also if wheat is threshed before it is dry enough, and allowed to stand in the sack or in a heap in the granary, that it " heats ". Wheat may also heat in the stack, and become damaged owing to the presence of too much sap

[1] Charles E. Saunders, " Quality of Wheat ", *Bulletin 57*, Central Experimental Farm, Ottawa, 1907.

[2] T. C. H. Bailey, " Marquis Wheat ", Milling Quality, *Bulletin No. 137*, Minnesota Wheat Investigations, Series II, University Farm, St. Paul, 1914.

in the straw. A stack of wheat harvested in damp weather will usually greatly improve in condition if allowed to stand until spring, as the winds of winter and spring dry the stack, and wheat which went into the stack slightly moist will often come out quite dry, especially if threshed in dry weather.

The other qualities of the grain mentioned depend to a considerable extent upon the variety of wheat grown, and it is unfortunately true that most British wheats are very inferior in quality to the best Canadian and American grain.

The Home-grown Wheat Committee, under the chairmanship of Mr. A. E. Humphries, has been engaged for a number of years in investigating wheats which are likely to prove of high quality when grown in this country. It would appear from these investigations that, although well-harvested English wheat is quite suitable for certain purposes which would absorb relatively small quantities, it is relatively unsuitable for bread-making purposes, and, therefore, unable to compete satisfactorily with foreign wheat, whereas to secure maximum returns per acre to the grower it must be entirely suitable to the commercial requirements of millers in the districts where it is grown. The Committee also consider that, except when it is in exceedingly small supply, English wheat realizes poor prices, and its relative value must still further diminish if an increased quantity of the unimproved article be placed on our markets.

It is recognized that as a commercial proposition it is impossible to compensate growers for substantially diminished yields per acre by improved quality of grain.

The work of the Committee has been directed to the production, by means of hybridizing and Mendelian selection, of varieties possessing high yield, high resistance to disease, and high milling quality.

Certain of the wheats tested by the Committee retain their strength under British conditions, and one of them—Red Fife—has proved a most valuable wheat to act as one parent of varieties which Professor Biffen has produced by cross breeding.

It appears that the " quality of endosperm " which gives to the flour the highest quality for bread-making can be handled as a separate Mendelian unit, and therefore can be transmitted from an otherwise undesirable parent to highly desirable progeny.

Manuring as ordinarily practised by farmers, or as exemplified at Rothamsted and Woburn, and rotation of cropping have no appreciable beneficial effect on the quality of wheat.

It also appears that, conditions being similar, autumn-sown wheat is as strong as spring-sown wheat, and that early cutting of wheat does not result in greater strength in the bakery, although it has often been thought that this was the case.

Susceptibility and immunity to disease are also Mendelian units, and

immunity or high resistance to rust found in, or conferred on, a variety greatly increases its yield of grain and straw, and indirectly improves the quality of both.

The quality of wheat from a milling and baking point of view can best be tested by actually milling the wheat and making bread of the flour, and it is by actual baking tests that the strength of the newer varieties has been tested, and the many problems connected with the strength of wheat flour have been investigated.

When only small quantities of a variety of wheat are available, much valuable information may be obtained by the "chewing" test. If a few grains of wheat are taken and chewed in the mouth, an elastic mass is obtained which varies greatly with different varieties of wheat. As a rule the more elastic the mass the bigger the loaf that can be made from the flour, i.e. the better the baking qualities. The colour of the mass is also a good indication of what the flour produced will be. The colour should be pale cream or whitish—not too yellow, and when this is the case the flour produced will be lighter and more attractive looking.

It will be seen that the question of quality in British wheat is a difficult one, owing to the fact that most high quality wheats do not give a sufficiently heavy crop in this country, and therefore do not give such a high financial return per acre as the lower quality wheats.

One of the more recent cross-bred wheats introduced by Professor Biffen—Yeoman—promises to be very valuable in bridging the gulf between quality and quantity. Much work has been done on this question by various investigators, and those who desire to study the subject further will find the following publications useful:

Supplement to the Journal of the Board of Agriculture, June, 1910, being papers read on wheat at a meeting of the British Association held at Winnipeg, August, 1909.

Reports published by the Home-grown Wheat Committee (59 Mark Lane, London, E.C.).

"The Question of Quality in Wheat", Sir A. D. Hall, *Journal of the Board of Agriculture*, 1904, 11, 321.

"Causes of the Quality Strength in Wheat Flour", A. E. Humphries, *Report Brit. Assoc.*, Leicester, 1907. See also *The Miller*, 1907, p. 414 (2nd September).

"The Chemistry of the Strength of Wheat Flour", T. B. Wood, *Journal of Agricultural Science*, 1907, 2, 139–61; 267–77.

"Milling and Chemical Values of Grades of Wheat in Manitoba", C. E. Saunders and F. T. Shutt, *Bulletin*, Canadian Experimental Farm, No. 50 (1904), No. 60 (1907).

Essays on Wheat, Professor A. H. R. Buller, Manitoba University (New York, The Macmillan Company, 1919).

Most of these publications can be borrowed from the library of the Ministry of Agriculture (10 Whitehall Place, London).

Conclusion

Wheat growing in the United Kingdom was for the thirty years preceding the outbreak of the Great War carried out under serious difficulties. The virgin soils of the West poured their wheat into this country at a price with which the home grower found it difficult, and sometimes impossible, to compete. There can be no doubt that for several years in the "nineties" wheat growing was carried on at a loss in Great Britain. Nevertheless the British farmer manfully endeavoured to carry on as best he could, and the outbreak of war found him still with a respectable acreage of our most important cereal, although, from the point of view of national safety, that acreage was deplorably small. Without this wheat, however, we should indeed have been in a sorry plight.

What the future has in store for the British wheat grower no one can say. The Agriculture Act of 1920, which was undoubtedly a sincere attempt to maintain or increase the area under wheat and oats, was soon scrapped.

The application of science and scientific methods to wheat growing is a sure way of effecting an improvement. Already much has been accomplished in this direction by better methods of manuring, and by the introduction of better varieties of wheat, but much more may be expected in the future both from research and from the spread of the very considerable store of information already available. The rapid extension of mechanical tillage will also greatly help the heavy land farmer—who is our principal wheat grower—in that it enables him to get his land quickly ploughed in the autumn before it gets wet and sticky.

There can be little doubt that any increase in the average production of wheat per acre in the future must depend to a considerable extent upon the introduction of improved varieties, and upon more scientific manuring. In the actual cultivation of the land—ploughing, &c.—there is also room for considerable improvement, especially in counties where the area under tillage is relatively small. In some districts, however, methods of cultivation have already reached a very high standard, but nevertheless the extensive adoption of mechanical tillage will probably result in the cultivations being performed quickly when the land is in a suitable condition, also in it being kept cleaner, and consequently, for these reasons, in rather larger crops being obtained.

It is a matter for regret that more has not been done by local and county agricultural societies, farmers' clubs and unions, towards the improvement of agriculture in general. Their activities have in great measure been restricted to the improvement of live stock; and whilst it is true that good work has also been done in organizing competitions in farm manual

processes, such as ploughing, drilling, hoeing, &c., much more might be done in that direction. If the farm-worker could be encouraged to perform the operations necessary in the cultivation not only of wheat but of other crops more skilfully, there can be little doubt that production would be increased. If competitions were organized by local agricultural bodies, and prizes given for the best and most skilfully cultivated field of wheat in the district, that also would undoubtedly tend to improve the average standard of wheat growing.

So long as man looks to the fruits of the earth for his sustenance, so long in all probability will wheat remain his principal food. Upon the energy and resourcefulness which are put into the work of growing the grain will depend to some extent the future of civilization. We may be well assured that in the time to come, as in the past, " he that tilleth his land shall be satisfied with bread ".

CONTINUOUS WHEAT GROWING

By Sir JOHN RUSSELL, D.Sc., F.R.S.

The regular method of growing wheat in England has been, from time immemorial, in a rotation, but a certain number of records exist of wheat grown continuously on the same land for many years. The most famous long continued succession is the one on the Broadbalk field at Rothamsted, where wheat has been growing every year without a break since 1843. The object of the experiment in the first instance was to find out if the crop would grow in this continuous manner, and, if so, what its food requirements would be. The experiment was repeated at Woburn on a lighter and more sandy soil, beginning in the year 1877; here also the wheat has been grown every year without a break right to the present time. At the Ottawa Experimental Station, Canada, and the Minnesota Experimental Station in the United States, the same course has been followed—wheat has been grown continuously on the same land since 1888 and 1893 respectively.

The experiments have proved that wheat can perfectly well follow wheat, but they do not show whether the scheme is feasible in practice. The experiments are difficult to carry out; there is always more trouble in keeping the land clean than where a rotation is adopted. Better information as to the commercial possibilities is afforded by the experience of Mr. Prout, of Sawbridgeworth, who grew wheat from 1864 to 1911 on the same land with only occasional changes, and found the results

profitable. In many parts of Canada and of the United States continuous wheat growing is common, but it is recognized as bad practice, and it is being displaced by rotations.

The following account is divided into two parts: the first dealing with the conditions necessary for the continuous growth of wheat, and the effect on the soil, &c., as shown by the Rothamsted experiments; the second with the practicability of the method on the large scale.

CONDITIONS NECESSARY FOR THE CONTINUOUS GROWTH OF WHEAT

1. **Weeds must be kept Down.**—Few farm crops will withstand the competition of weeds, and wheat specially suffers unless great precautions are taken to keep the land clean. On the heavy land at Rothamsted, as on some of the heavy land of Essex, the most troublesome weed is the black bent grass, *Alopecurus agrestis*, which grows up in the wheat and sheds its seeds a little before the crop is cut. The wheat is not usually harvested till the end of August; the new crop ought to be sown in October, so that only in the month of September is any cleaning possible. Very little is practicable if the weather is too dry or too wet, or if the harvest is drawn out and labour is short. The result is a large admixture of grass with the wheat, which is apt to cause a great deal of trouble. The crop on continuous wheat land is very dependent on favourable weather in the August and September before the seed is sown.

An interesting demonstration of the absolute necessity for keeping the land fairly clean is afforded by the so-called Wilderness on the Broadbalk field. In 1882 the weather at harvest-time was so bad that part of the wheat outside the experimental area could not be cut, and was therefore left standing all through the winter. In the spring some of the shed seed germinated and produced a crop which seemed so interesting that the area was shut off and has been left untouched and unharvested ever since. The first self-sown crop was fully recognizable as wheat, but there were quantities of weeds. The second self-sown crop was feeble, the weeds having really exterminated the wheat. In the third year only little wheat was left; while in the fourth year a careful search had to be made before any wheat could be found, and then the plants were abnormal. They were very stunted, not more than 6 inches high, and carried only a few grains per head. It was at first supposed that degeneration had taken place, but more probably the original wheat was somewhat mixed, and contained a small amount of this stunted kind of wheat, which stood the competition of weeds better than the ordinary larger form.

2. **Manure must be Added.**—If weeds are kept down, a crop of wheat is obtained however poor the soil, even if no manure is supplied; but the crop is only small. At Rothamsted it long remained at $10\frac{1}{2}$ to

12½ bushels per acre, to which figure it sunk after the first twenty-five years of the experiment. From 1872 to the present day there has been only a small drop in the yield although no manure has been supplied since 1839, i.e. for a period of eighty years. The figures are:

	8 Years, 1844–51.	10 Years, 1852–61.	10 Years, 1862–71.	10 Years. 1872–81.	10 Years, 1882–91.	10 Years. 1892–1901.	10 Years, 1902–11.	10 Years, 1912–21.
Grain, bushels per acre ..	17·2	15·9	14·5	10·4	12·6	12·3	10·9	8·7
Straw, cwt. per acre ..	15·5	15·2	11·5	8·5	8·5	9·1	9·6	7·8

An average crop on this plot removes from the soil about 18 lb. of nitrogen, 9 lb. of phosphoric acid, and 14 lb. of potash per annum; in addition, over 10 lb. of nitrogen are lost by drainage—figures which are very small in comparison with the reserves still present in the soil; about 2500 lb. of nitrogen, 3000 lb. phosphoric acid, and 50,000 lb. of potash, much of which, however, is almost unavailable to the plant.

While the yields obtained on this unmanured land seem small to an English grower, they are not small in comparison with those obtained in other countries. For example, the average yields of wheat in the following countries were, before the war:

	Bushels per Acre.		Bushels per Acre.
United States ..	14	Australia	8 to 11
European Russia ..	9	France	20·8
Canada	19	United Kingdom ..	32·6

There is no sign of any falling off in quality on the unmanured plot at Rothamsted. The grain is as large, as heavy per bushel, and of the same market value as that grown on any other plot. Further, many individual heads are nearly as good as any on the field, but there is a great difference in the amount of tillering. The figures are:

Character of Grain as Affected by Manuring.

	Plot.	Valuer's Mark.	Offal Grain to 100 of Dressed Grain.	Weight per Bushel of Dressed Grain, Pounds.	Grain to 100 of Straw.
Farmyard manure	2	102·3	3·8	61·3	56·7
Complete artificials ..	7 and 13	101·0	3·6	61·0	57·3
Complete artificials with additional nitrogen ..	8	100·8	4·2	60·8	51·5
Nitrogen and phosphate only, no potash	11	97·1	7·4	58·6	59·5
Nitrogen only, no phosphate or potash	10	98·7	6·1	59·6	66·6
No manure	4	100·3	4·3	60·7	77·2

The Rothamsted crop of 12 bushels, obtained without manure, can be increased considerably by the use of manure. This is shown in Table I.

Effect of Nitrogenous Manures.

The extraordinary feature of the result is the remarkable effect of nitrogenous manure on the yield of the wheat shown in fig. 1. There is, of course, a limit to the crop, but it is not easily reached; and within this limit the addition of more nitrogen further increases the yield, according to the amount supplied.

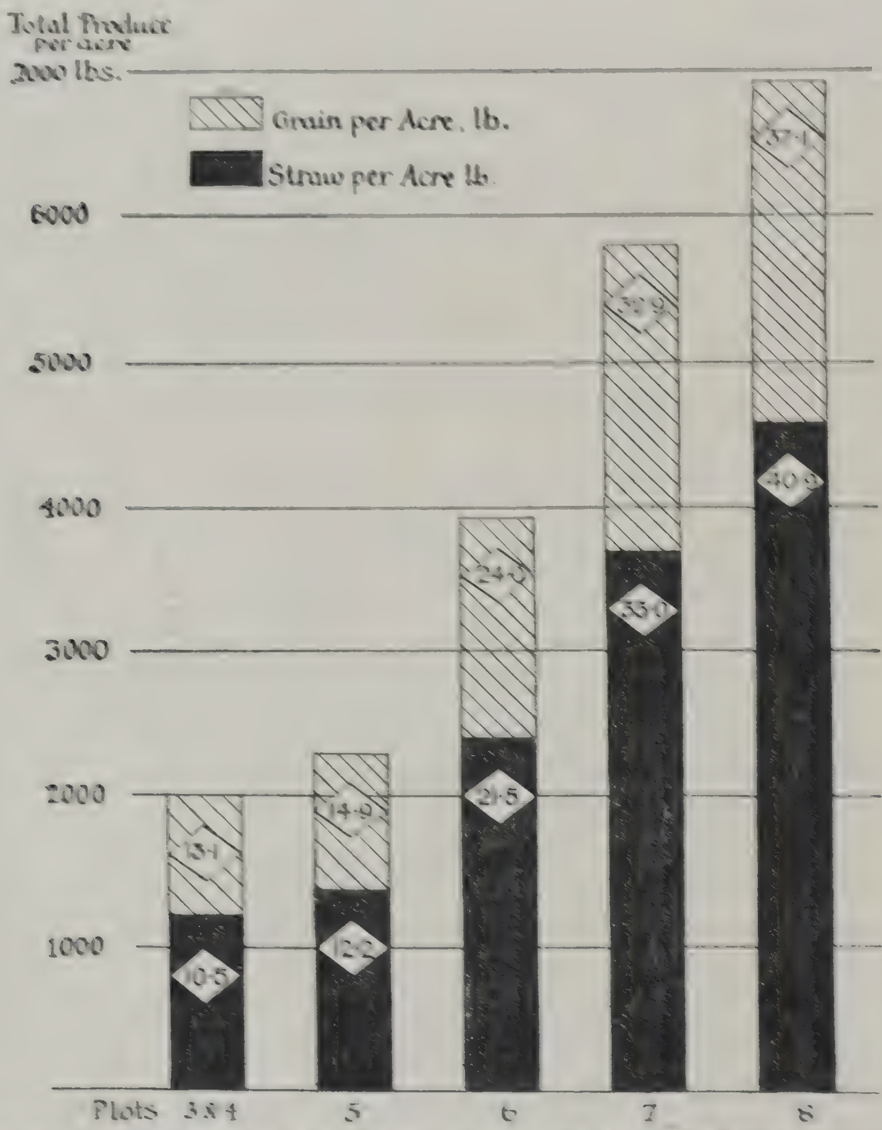

Fig. 1.—Broadbalk Wheat. Effect of increasing amounts of nitrogen on the production of wheat (grain and straw). Average, 51 years (1852–1902).

Plots 3 and 4, no manure. Plot 5, phosphates, potash, &c., but no nitrogen. Plot 6 as 5, but with sulphate of ammonia containing 43 lb. nitrogen per acre. Plot 7 as 5, but with sulphate of ammonia containing 86 lb. nitrogen per acre. Plot 8 as 5, but with sulphate of ammonia containing 129 lb. nitrogen per acre.

From Rothamsted *Guide to the Experimental Plots*, 1913, by permission of Mr. John Murray.

Nitrogen supplied as—	0	43	86	Pound nitrogen per acre supplied in manure.
Sulphate of ammonia ..	15·4	23·5	32·4	Bushels of corn obtained.[1]
Nitrate of soda	15·4	27·3	32·5	

On the first set of plots the nitrogen is supplied as sulphate of ammonia. A somewhat better result is obtained with nitrate of soda as shown in the lower line. No other fertilizer behaves in the same way as these. Additional quantities of phosphate and potash beyond the necessary amount have no effect in increasing yield.

The very close relationship between nitrogen supply and yield causes the wheat crop to be much affected by weather. A wet winter washes away much of the nitrate from the soil; it therefore considerably reduces the yield of wheat per acre.

Thus, on the dunged plot the yields are:

After wet winters[2]	32·5	bushels per acre
After dry winters	36·9	,, ,,

This relationship is quite general. Sir Napier Shaw has shown that, speaking generally, each inch of autumn and winter rain causes a regular loss of yield throughout the eastern counties.

The nitrogen lost by rain may, however, be made good by spring dressings. Where nitrate of soda or sulphate of ammonia is applied to the plots in spring there is much less falling off in yield than otherwise occurs. Indeed in many cases, though not always, there is none.

	Sulphate of Ammonia Applied in Autumn (No Spring Dressing).	Sulphate of Ammonia Applied in Spring (Spring Dressing).[3]
After wet winters ..	27·5	32·5
After dry winters ..	31·8	32·5

The bad effect of wet winters is probably not entirely due to washing out of nitrates; there is also a restriction of root development which seriously affects the subsequent growth of the plant. On the whole the best yields are obtained in seasons where the winter is dry, the spring sufficiently warm and wet to allow of copious growth, and the summer sufficiently dry and warm to allow of satisfactory ripening.

Effect of Phosphatic Fertilizers.

Of the other fertilizers, phosphates come next in importance on heavy soil. This is not so well brought out by the Rothamsted experiments

[1] 1893–1902, a typical ten-year period.
[2] For details see *Jour. Agri. Sci.*, 1914, Vol. VI, p. 19.
[3] *Ibid.*, p. 18.

as it might have been, but of late years a plot has been added to show up the phenomena more distinctly. The omission of phosphate caused an immediate drop in the yield of grain and straw, but the experiment is complicated by the simultaneous omission of potash, which, however, would produce little effect in the first years. Experience elsewhere proves that phosphates hasten the ripening of wheat, and therefore make the harvest earlier by several days—sometimes as much as ten or twelve days—than would otherwise be the case. This is a very important consideration in wet and late districts, or where for any reason an early and speedy harvest is desirable.

Effect of Potassic Fertilizers.

On light soils potash is more important than phosphates. Its effect is shown at Rothamsted both in yield and vigour of crops. Where potash is supplied in addition to the other nutrients the yields are good and the plant is healthy; where, on the other hand, potash is withheld the yields fall off and the plant loses vigour; it takes disease easily, and in bad seasons is liable to be smothered in rust, while surrounding plots supplied with potash escape more lightly. The effect of withholding both potash and phosphate is shown below and in Table I: the yield of total produce, once 2000 lb. per acre below the plot (No. 6) receiving potash, has fallen off by a further 1000 lb. per acre, and is now 3000 lb. below; the effect on grain and straw separately is:

Nitrogen Supplied and in Addition	Grain, Bushels per Acre.		Straw, Cwt. per Acre.	
	First Ten Years.	Last Ten Years.	First Ten Years.	Last Ten Years.
Potash and phosphate ..	32·9	32·1	34·4	35·8
No potash, phosphate only	28·4	19·2	28·2	21·7
No potash or phosphate ..	23·2	18·4	24·5	18·0

These figures show that potash starvation did not quickly set in even after potassic fertilizers ceased to be added, but finally it produced striking effects.

Another experiment shows, however, that potash starvation can be deferred for many years by additions of a sodium salt. The particular one used is sodium sulphate, and Plots 11, 12, and 13 (Table I) show how it delayed the falling off in yield. Instead of the sulphate, another compound, the chloride—better known as common salt or agricultural salt—might have been used with similar effect. The need for potash is more felt on light soils and chalky soils, and on these salt is a recognized fertilizer.

Effect of Continuous Wheat Cropping on the Soil.

When nitrogen, potash, and phosphate are supplied to the wheat crop the yield keeps up. It fluctuates from season to season, and the relative proportions of straw and grain vary somewhat, but the total produce is never far below, and is commonly up to 6000 lb. per acre, while the grain varies from 32 to 35 bushels. There is no obvious sign of falling off in yield or vigour, and none of the "sickness" that was so confidently predicted by critics in the early days; nevertheless, a fuller investigation shows that there is a steady diminution in yield. The percentage of nitrogen in the soil is barely maintained, and on the unmanured plot it has fallen off: when the experiment began in 1843 the percentage was 0·125; in the latest sample of 1914 it was only 0·095. The figures are:

NITROGEN PER CENT

	Plot.	1843.	1865.	1881.	1893.[1]	1914.[1]
No manure ..	3	0·125[2]	0·105	0·101	0·099	0·095
Complete artificials	7		0·117	0·124	0·122	0·113
Farmyard manure..	*2b*		0·175	0·184	0·221	0·260

NITROGEN, POUNDS PER ACRE

	Plot.	1843.	1865.	1881.	1893.[1]	1914.[1]
No manure ..	3	3260[2]	2722	2616	2570	2470
Complete artificials	7		3034	3129	3170	2930
Farmyard manure..	*2b*		4343	4400	5150	6180

It is impossible to foretell how this falling off in nitrogen content of the soil will ultimately affect the crop; experience with other plots suggests the change will be rapid when it comes.

Effect of Farmyard Manure.

The effect of farmyard manure is very striking. Apart from the specially bad harvests of 1875, 1876, 1877, and 1879, there has been a steady rise in yield, which is still continuing, though now very slowly.

[1] The 1893 and 1914 results are not strictly comparable with the earlier ones, as the nitrogen was determined in a different way (the Kjeldahl method), which gives rather higher results than the old soda lime method. About 200 lb. per acre would probably have to be added to the 1865 and 1881 results to make them comparable with the later ones. [2] Dr. Gilbert's estimate.

In the beginning the total yield was about 4800 lb. per acre; it has gone up steadily, and is now just under 7000 lb. The plot thus differs from those receiving artificials. At best the artificials have only maintained their original effects. A further important feature is the greater steadiness of the yield from season to season. This is shown in fig. 2, where the fluctuations on the plot receiving farmyard manure are seen to be less than where complete artificials are given.

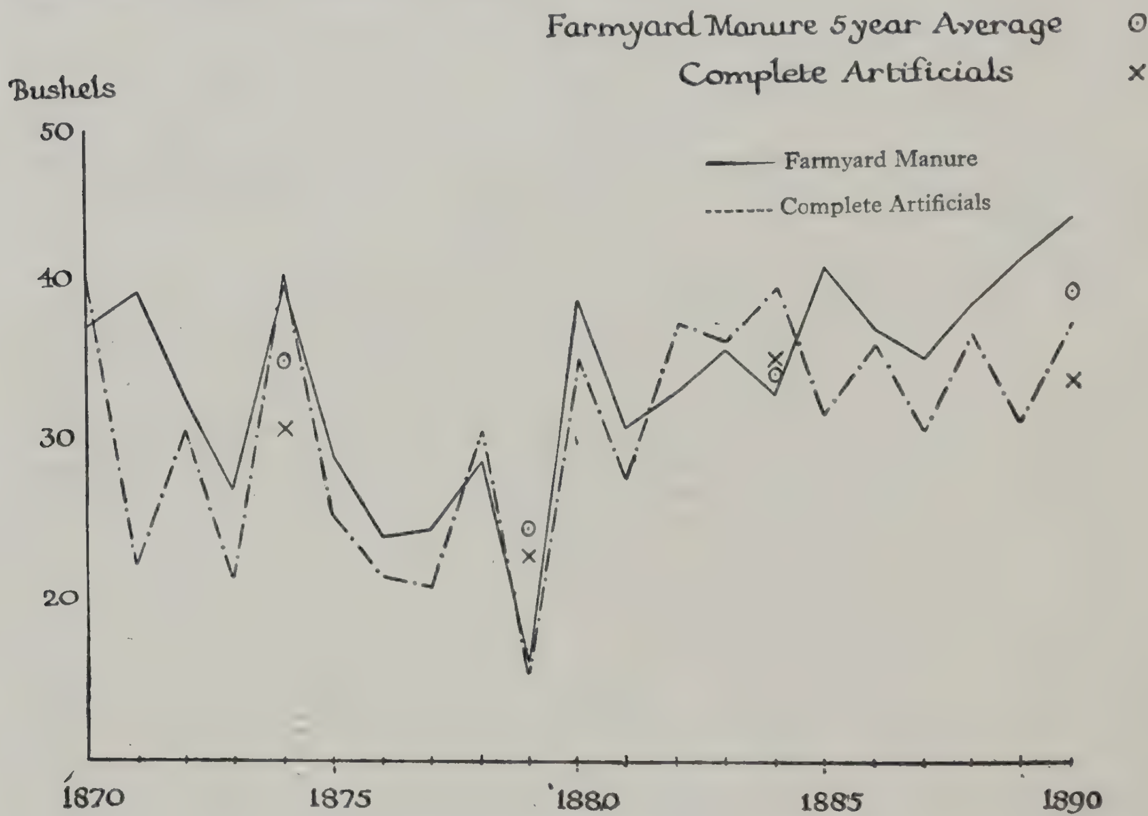

Fig. 2.—Effect of Fertilizers on Wheat—Broadbalk

It thus appears that farmyard manure possesses advantages over artificials. In the Broadbalk experiment it has one disadvantage—its greater cost. The amount used is sufficient to supply 200 lb. of nitrogen per acre; the actual weight therefore depends on the richness, but it is usually round about 13 tons per acre, and it is put on every year. Very few farmers have sufficient farmyard manure to dress all their wheat at this rate, and even if they could buy it the cost would be prohibitive—not less than £7 per acre by the time it was spread on the land. Artificials are much less expensive and are therefore more practicable where money is an object.

COMPARISON OF CONTINUOUS WHEAT CROPS WITH THOSE GROWN AFTER FALLOW

These experimental results can be compared with two others on the Rothamsted fields. Wheat is grown after fallow on the Hoos field; first a year of bare fallow, then a year of wheat, then bare fallow, then wheat, and so on indefinitely. No manure is supplied. Usually the crop following the fallow is higher than the Broadbalk unmanured crop, but the difference depends on the season. In dry years the fallow proves very beneficial; in wet years it is little help. The results are:

	Rain.	Total Produce, Pounds per Acre.				Grain, Bushels per Acre.			
	Oct.–March.	Broadbalk Continuous.	Hoos after Fallow.	Difference in Favour of Growing after Fallow.		Broadbalk Continuous.	Hoos after Fallow.	Difference in Favour of Growing after Fallow.	
	Inches.			Per Acre.	Per Cent.			Per Acre.	Per Cent.
Low winter rainfall ..	11·73	1898	2632	+ 734	+ 39	12·4	16·2	+ 3·8	+ 31
High winter rainfall ..	16·73	1795	2085	+ 290	+ 16	11·7	12·8	+ 1·1	+ 9

The explanation of the differences seems simple. During the fallow period the land is becoming enriched in nitrates, so that at the time of sowing there is a supply of nitrogenous nutrients. On the previously cropped land, on the other hand, no opportunity is afforded for the accumulation of nitrates, and the young crop is not nearly so well supplied. It is already shown in fig. 1 how completely dependent is the wheat plant on an ample nitrogen supply. If the season is dry the nitrates remain in the soil and are available for the young plant; if, however, there has been much rain the nitrates are washed out and the fallow land loses its advantage over the cropped land.

From the practical point of view it is more instructive to compare the Broadbalk results with those obtained on Agdell field, where the wheat is grown in rotation. Unfortunately the experiment is so arranged that only one crop is grown at a time. Comparison cannot be made every year, but only every fourth year. If the experiment were being restarted it would be better to divide the field into four portions, each, while under rotation, carrying a different one of the four or five component crops, so that each crop would be grown somewhere on the field every year. Continuous comparison with Broadbalk would then be possible. In the repetitions of the experiment carried out at State College, Pennsylvania, since 1885, and at Wooster, Ohio, since 1894, this arrangement was adopted, and it allows many instructive deductions to be drawn from the results.

The most important conclusions indicated by the Rothamsted experiments are that a given crop is more easily obtained in rotation than under continuous wheat culture. Owing to differences in the method of manuring it is difficult to compare the yields except on the unmanured plots, and here the rotation proves distinctly the best:

Continuous Wheat.	After Fallow.	In Rotation.
11·8	17·2	26·9 bushels per acre

But there is far less fluctuation in bad seasons on the rotation plots than on the continuous plots; the clover residues presumably exert a steadying effect on the wheat.

Steadying Effect of Crop Residues on Yield of Wheat.

	After Clover Ploughed in; complete Artificials.	After previous Wheat Crop; complete Artificials.
Average of all ..	35 bushels	30 bushels
Highest yield, 1863	46 ,,	56 ,,
Low yields .. 1871	25 ,,	13½ ,,
Low yields .. 1875	31 ,,	11 ,,
Low yields .. 1879	13 ,,	5 ,,
Low yields .. 1903	28 ,,	24 ,,

Further, the great difficulty of cleaning the land, which makes the Broadbalk wheat crop one of the most expensive in the country, is considerably reduced on the rotation field. Two of four crops in the rotation allow of cleaning operations: the barley crop during autumn, winter, and early spring, and the root crop during a good deal of the summer in addition. When continuous wheat is grown, however, there is only a little time between harvest and sowing, and nothing effective can be done unless one has steam or motor tackle and favourable weather.

From a practical point of view the rotation has so many advantages that it completely holds the field against continuous wheat growing. There are, however, a few cases on record where wheat has been grown continuously on the same land for a number of years at a profit. Jethro Tull, in the early part of the eighteenth century, grew thirteen wheat crops in succession on the same land at Hungerford, in Berkshire. In the last generation, Prout, of Sawbridgeworth, and his son grew wheat on the same field from 1864 to 1911 with only rare breaks when barley or clover were taken. The Prouts found the scheme profitable, but their successor did not attempt it, and the field is now cropped in a more ordinary way.

EXPERIMENTS ON WHEAT: BROADBALK FIELD AVERAGE PRODUCE OF GRAIN AND STRAW PER ACRE THE FIRST EIGHT YEARS (1844–51), AND OVER THE SUCCESSIVE TEN YEARS (1852–1911) INCLUSIVE

Plot	Abbreviated Descriptions of Manures	Averages: 8 years, 1844–51	10 years, 1852–61	10 years, 1862–71	10 years, 1872–81	10 years, 1882–91	10 years, 1892–1901	10 years, 1902–11
	DRESSED GRAIN							
		Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.
2	Farmyard Manure	28·0	34·2	37·5	28·7	38·2	39·2	35·1
3	Unmanured	17·2	15·9	14·5	10·4	12·6	12·3	10·9
5	Minerals	—	18·4	15·5	12·1	13·8	14·8	13·5
6	Single Ammonium-salts and Minerals ..	—	27·2	25·7	19·1	24·5	23·1	21·4
7	Double ,, ,, ..	—	34·7	35·9	26·9	35·0	31·8	30·9
8	Treble ,, ,, ..	—	36·1	40·5	31·2	38·4	38·5	37·2
10	Double Ammonium-salts alone	25·1	23·2	25·1	17·3	19·4	18·4	18·4
11	,, and Superphosphate	—	28·4	27·9	21·7	22·7	19·5	19·2
12	Double Ammonium-salts, Superphosphate, and Sulphate of Soda	—	33·4	34·3	25·1	30·1	26·7	27·4
13	Double Ammonium-salts, Superphosphate, and Sulphate of Potash	—	32·9	34·8	26·8	32·5	29·6	32·1
14	Double Ammonium-salts, Superphosphate, and Sulphate of Magnesium	—	33·5	34·4	26·4	31·1	25·0	25·0
	STRAW							
		Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
2	Farmyard Manure	26·6	33·9	34·0	28·0	34·8	38·7	40·9
3	Unmanured	15·5	15·2	11·5	8·5	8·5	9·1	9·6
5	Minerals	—	17·1	12·8	9·7	9·9	11·5	12·4
6	Single Ammonium-salts and Minerals ..	—	26·3	22·8	17·7	20·5	20·0	22·4
7	Double ,, ,, ..	—	36·4	34·3	28·7	34·1	31·1	35·4
8	Treble ,, ,, ..	—	40·5	43·2	36·6	42·5	41·7	45·5
10	Double Ammonium-salts alone	23·7	24·5	21·9	15·2	15·8	16·2	18·0
11	,, and Superphosphate	—	28·2	24·5	21·3	20·8	18·8	21·7
12	Double Ammonium-salts, Superphosphate, and Sulphate of Soda	—	34·2	30·5	25·0	27·3	24·0	28·6
13	Double Ammonium-salts, Superphosphate, and Sulphate of Potash	—	34·4	33·4	27·6	31·9	28·6	35·8
14	Double Ammonium-salts, Superphosphate, and Sulphate of Magnesium	—	35·0	30·7	26·3	28·6	23·4	26·3

The most important examples of continuous wheat growing are found in Canada, the United States, and Australia, where many instances occur of twenty or even thirty crops raised on the same land with only rare breaks. But the same phenomena appear as on the Broadbalk wheat field: the crop is liable to great seasonal variations and the soil is steadily losing nitrogen. The only way of avoiding these undesirable features is to introduce a proper rotation.

PRODUCTS OF WHEAT

By T. B. WOOD, C.B.E., M.A., F.R.S.

WHEAT

The grain of this cereal is the most important item in the food-supply of the United Kingdom. It is authoritatively estimated to have contributed during the period 1909–13 30 per cent of the energy value of the human food consumed by the whole population. Wheat is eaten chiefly in the form of bread, which accounts for 26 of the above-mentioned 30 per cent.

During the same period the total annual wheat supply of the United Kingdom was 7,255,000 tons, of which only 1,584,000 tons was home-grown, the remaining 5,671,000 tons having been imported. By no means the whole of the 7¼ million tons was used for human food. About 130,000 tons were required every year for seed. Various industries, such, for instance, as starch manufacture and the making of paste, are estimated to have absorbed about 125,000 tons.

Animals consumed about 2,000,000 tons, partly in the form of tail and damaged corn, but chiefly as millers' offals. Only about 5 million tons of flour were therefore extracted from the total 7¼ million tons of wheat for human consumption.

These figures—which are quoted from the *Report of the Food (War) Committee of the Royal Society*, Cd. 8421, and from *The National Food Supply in Peace and War*, by T. B. Wood—serve to show the immense importance of wheat as a source of human food.

The nutrient ratio of wheat is 1 : 7·5, the starch equivalent for production 71·6, and the number of food units per ton 90. Wheat normally weighs 63 lb. to the bushel.

The average chemical composition of wheat is as follows:

	Percentage Composition.	Digestible Nutrients, Per Cent.
Water	13·4	—
Protein	12·1	10·2[1]
Fat	1·9	1·2
Carbohydrates	69·0	63·5
Fibre	1·9	0·9
Ash	1·7	—
	100·0	

Home-grown wheat normally contains about 16 per cent of water, but this figure is subject to considerable variation. In wet seasons it may rise to as much as 18 per cent, and in very dry seasons it may fall as low as 12 per cent.

Foreign wheats are on the whole considerably drier than home-grown samples. In Russian wheats, for instance, the percentage of water is usually 12; and this is the usual figure for most American, Canadian, Argentine, and Australian wheats. Indian wheats, and wheats from the western states of America and parts of Australia, often contain under 10 per cent of water. With wheat at its present price, about 75*s.* per quarter, foreign samples, which contain on the average 5 per cent less water than home-grown samples, are worth on this account alone from 3*s.* 6*d.* to 4*s.* per quarter more than home-grown samples.

Wheat contains several different proteins, only one of which is of any practical importance, namely, gluten, which is readily separated from flour as follows: The flour is tied up in a piece of fine muslin, moistened with water, and allowed to stand for a short time. It is then rubbed between the fingers in a stream of water. In this way the starch grains are washed away, and the gluten remains in the muslin as a somewhat sticky elastic mass. Gluten prepared in this way is a mixture of two proteins, gliadin and glutenin. Gliadin is easily soluble in 70 per cent alcohol. Glutenin only dissolves in alcohol of this strength if it is made distinctly alkaline.

The fat of wheat is a yellowish oil and needs no special comment.

The carbohydrate of wheat is almost entirely starch, though small quantities of sugar, gum, and cellulose are also present.

The composition of the wheat grain is not the same throughout. The cellulose and fibre are present in the greatest proportion in the husk or seed coats. The protein is most abundant in the layers of cells which lie immediately in contact with the seed coats. The fat accumulates chiefly in the embryo. Since the husk and seed coats, with a certain

[1] Containing pure protein 9 per cent.

proportion of the adherent layers, are removed in milling and sold as bran or other millers' offals, and since a considerable proportion of the germ is also removed and sold separately, the flour contains a lower percentage of protein, fat, and fibre than does the grain from which it was obtained.

Gluten possesses peculiar physical characters which enable it to retain the carbon dioxide gas formed in the dough by fermentation of the sugars of the flour by the yeast. In this manner the dough is filled with bubbles of gas, and a spongy loaf results on baking. No grain except wheat contains a protein possessing such characters. Consequently no other grain can yield spongy bread.

The flour of different wheats varies greatly in behaviour on baking. Some wheats yield flour which makes shapely loaves of good texture; such wheats are known by millers as strong wheats. Other wheats yield flours which make flat, heavy loaves and are known as weak wheats. Strong wheats are as a rule thin-skinned and translucent, weak wheats thick-skinned and opaque. Strong wheats when cut across look waxy inside, weak wheats mealy. The strongest wheats are grown in Hungary, certain parts of Russia, Canada, and the northern states of America. Argentine wheats, and some Indian wheats, are fairly strong. The wheats of the western and southern states of America and of Australia are usually weak.

Until recently it was considered impossible to grow strong wheats in the United Kingdom. It is now definitely established, through the work of the Home-grown Wheat Committee, and particularly of Professor R. H. Biffen of Cambridge, that certain varieties of wheat, notably Red Fife, retain their strength when grown in England. This variety is the chief constituent of the best grades of American and Canadian strong wheats. It is, however, a poor yielder in this climate, but Professor Biffen has produced crosses from it which yield as well as, or better than, the standard British varieties, and produce grain as strong as that of their Fife parent.

Sound wheat is not ordinarily used to any great extent for feeding live stock. Generally its price is too high for economical use as a feeding stuff. Whilst prices were controlled during the Great War, wheat and wheat flour became actually cheaper than many common feeding stuffs, and it was necessary to forbid their use for feeding live stock in order to maintain the bread supply.

A certain amount of tail or damaged wheat is used on the farm, chiefly for feeding pigs and poultry. Its feeding value is approximately the same as that of barley. Except for poultry it should be ground or crushed before use. Since wheat contains less fibre than barley or oats, and since its protein becomes very coherent when moistened, wheat, if fed alone, tends to become so sticky when chewed that it is almost unpalatable. For this reason it should be mixed with other feeding stuffs con-

taining more fibre, for instance, bran, dried grains, chaff, &c., which will correct this property.

WHEAT OFFALS

Before the Great War approximately 7 million tons of wheat were milled annually in the United Kingdom, yielding about 2 million tons of offals—more than one-sixth of the whole amount of concentrated food consumed by the live stock of the country.

Innumerable analyses have been recorded of millers' offals, but their interpretation is a matter of considerable uncertainty, because of the lack of uniformity in nomenclature and the variation in the methods of separation.

Investigations made at Cambridge on a large number of samples, collected from typical mills in widely separated districts in 1916, showed that offals might be classified into four grades, as follows:

Grade 1, usually called "fine middlings", which passes through silk sieve No. 3, but not through silk sieve No. 10.

Grade 2, usually called "coarse middlings", which passes through wire sieve No. 24, but not through silk sieve No. 3.

Grade 3, usually called "pollards", which passes through wire sieve No. 16, but not through wire sieve No. 24.

Grade 4, bran, which does not pass through wire sieve No. 16.

The separations on which these grades were based were made by Mr. A. E. Humphries, of Coxes Lock Mills, Weybridge, who was also responsible for collecting the samples.

Analyses of several samples of each of these grades gave the following average results:

	Water.	Protein.	Fat.	Carbo-hydrates.	Fibre.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Grade 1.—Fine Middlings ..	12·73	15·75	3·44	63·80	1·86	2·42
Grade 2.—Coarse Middlings ..	13·46	16·42	5·03	56·22	5·29	3·58
Grade 3.—Pollards	13·32	14·39	4·76	55·50	7·70	4·33
Grade 4.—Bran	13·63	13·45	3·92	53·12	10·58	5·40

It will be noticed that the carbohydrates progressively decrease and the fibre and ash increase from the finer to the coarser grades. The protein and the fat are highest in the coarse middlings, probably because the germ accumulates in that grade.

Many of the samples collected were found, when submitted to sifting, to be mixtures of two or more of the above grades. Chemical analysis showed them to possess almost exactly the average composition of the grades of which they were composed. Thus:

	Water.	Protein.	Fat.	Carbo-hydrates.	Fibre.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Grades 1 and 2, which may be called straight run middlings	13·13	15·95	4·50	59·54	3·94	2·94
Grades 2 and 3, which may be called straight run pollards	13·70	16·32	5·25	54·52	6·17	4·04
Grades 1, 2, and 3, which may be called straight run offals	13·75	15·66	4·67	58·13	4·52	3·30
Grades 3 and 4, which may be called coarse pollards ..	14·93	14·69	4·29	53·98	7·36	4·75

The above figures may be taken as representative of the various grades of offals so far as they can be identified. Names, however, are but little guide to identification. Such local names as supers, randan, sharps, thirds, boxings, and so on give no definite indication as to the fineness or the composition of the samples to which they are applied. It is highly desirable that the Millers' Association or some other influential body should endeavour to ensure the general adoption of a definite system of grading throughout the country. If this were done, it would be worth while to carry out digestibility determinations of the different grades, for the results would be of general application.

As it is, the digestibility of wheat flour and bran are known. Assuming that the digestibility decreases regularly from flour to bran, the following figures may be taken as roughly representing the digestible nutrients, number of food units, and starch equivalent of the various grades.

DIGESTIBLE NUTRIENTS

Grade.	Protein.	Fat.	Carbo-hydrates.	Fibre.	Starch Equivalent.		Food Units.
					Main-tenance.	Pro-duction.	
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per 100 lb.		Per Ton.
Fine Middings	13·2	3·0	52·0	1·8	74	72	91
Coarse Middlings ..	13·8	4·3	45·5	5·0	74	64	92
Pollards	11·6	4·0	44·5	7·1	72	60	87
Bran	10·6	2·8	38·0	2·8	58	45	72
Straight Run Middlings	13·2	3·9	48·4	3·8	74	68	91
,, ,, Pollards	13·2	4·5	43·4	5·8	73	62	90
,, ,, Offals ..	12·8	4·0	47·0	4·4	73	66	89

The finer grades of offals are much used for feeding pigs, for milk substitute for calves—for which purpose they are mixed with ground linseed—and for cows kept in or near towns where roots and grain are not available. Bran is much used for cows and for horses. It contains a high proportion of fibre and ash, and the ash is particularly rich in

phosphate. It is distinctly laxative, and this property is more marked when it is given in the form of a mash. It is more suitable for growing, working, or milking animals than for fattening. The variety known as broad bran, the particles of which are larger, usually commands a higher price, though it does not appear to possess a higher food value.

WHEAT STRAW

As a fodder, wheat straw is tougher and less digestible than barley and oat straw, but being at the same time more elastic it is preferable to other straw for litter. In passing through the thrashing-machine, the straw is divided into the long straw, consisting for the most part of stems, and the cavings, which include broken stems and leaves. The chaff separated from the grain is also delivered separately. These three products—straw, cavings, and chaff—differ considerably in composition, as shown by the following analyses:

	Water.	Protein.	Fat.	Carbo-hydrates.	Fibre.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Wheat, spring straw ..	14·0	2·9	1·3	39·8	35·9	6·1
,, ,, cavings ..	14·0	8·6	1·1	42·7	22·7	10·9
,, winter straw ..	14·0	2·1	1·3	40·7	36·6	5·3
,, ,, cavings ..	14·0	3·8	1·8	39·8	32·2	8·6
,, ,, chaff ..	14·0	3·7	1·2	42·6	27·7	10·8

These analyses were recently made in Cambridge on a large number of samples collected from different districts. They probably give good average figures for the composition of the various products. They indicate very little difference in composition between the straw of winter and spring wheat. On the other hand, they show that cavings and chaff contain more protein, carbohydrates, and ash and less indigestible fibre than straw. Indeed some samples of cavings approximate in composition to hay. No reliable digestibility determinations of cavings or chaff are available, but there is no doubt that cavings have a higher feeding value than straw. The same is true of chaff, but the value of the latter is somewhat limited by the fact that it may irritate the eyes and noses of animals to which it is fed.

Wheat straw contains the following percentages of digestible nutrients: crude protein, 0·1; oil, 0·4; carbohydrates, 15·0; fibre, 18·3. Its nutrient ratio is very wide, 1 : 342. Its starch equivalent for production is only 11. For maintenance, however, its starch equivalent is considerably higher—34. Consequently its proper use is for maintenance of stock during the winter, and it should not be used in greater amounts than will suffice for this purpose.

OATS

By W. G. SMITH, B.Sc., Ph.D.

The oat belongs to the natural order of Grasses or grain-bearers (Gramineæ), the important group which includes all the cereals and many plants used for hay or forage. The genus *Avena* includes several more or less annual species, the parents of the cultivated varieties of oats. Tall Oat Grass and Golden Oat Grass are native perennial grasses, sometimes included under *Avena*, but recent authors tend to separate them as distinct genera.

The parent oats have large branched panicles, easily distinguished from the close ears of wheat, barley, and rye. From other grasses with an open panicle *Avena* is distinguished: (1) by the long, loose-fitting outer chaff or barren glume that encloses the cluster of grain-bearing flowers forming a spikelet; (2) by the awn or bristle, if present, being long, twisted, and attached below the tip of the flowering glume; (3) by the basal tuft of hairs often present at the base of the grain.

Early History.

Records show that the oat was known as a crop plant in ancient Europe, but not to the same extent as wheat and barley. It is not a crop suited to Mediterranean countries which were the centres of ancient civilization. Roman authors refer to the use of oatmeal by the savages of northern Europe, and when northern and western Europe became civilized countries, with records of their own, the oat appears as an important crop. An ancient Chinese record, about A.D. 600, refers to the chaffless variety still known as the naked oat of China.

The date of the introduction of the oat into Britain is uncertain, but in 1024 the *English Chronicle* gives the price of seed oats. During the fourteenth century oats and hay are mentioned as the food of ploughing oxen in England. In the seventeenth century the barley crop was greater than the oat crop, but from this time onwards the cultivation of the oat was rapidly extended, especially in the higher districts which were then being brought under the plough. In Europe the cultivation of the oat is largely carried on in Scandinavia, Denmark, North Germany, and parts

of Russia; but it has a strong competitor in rye, which has steadily increased in area since the Middle Ages. Southwards in Europe, the summer climate becomes drier, and the oat crop becomes limited to the cooler and moister mountainous countries.

Origin.

There is no definite information as to the origin of the cultivated oat. Several species of *Avena* occur in Europe as weeds in cultivated land, but they rarely become established and appear to be casual weeds rather than native species. There is a generally accepted view that the original oat is native either in south-eastern Europe or western Asia, but the preference of the oat for a cool, moist climate suggests that it came originally from cooler regions than wheat or barley. These conditions would be found in valleys such as the Danube, or those of the Caucasus and Lebanon. This view is supported by some of the older names—Tartarian, Hungarian, and Turkey—given to varieties with one-sided ears, and the frequent reference to Polish and Old Poland as older varieties with an open ear. The original seed of Siberian, now extensively grown in Canada, and Sixty-Day oats, a favourite in the United States, was in both cases imported from southern Russia. M. Trabut, in a recent monograph on his investigations, states that the common varieties of European oat (*Avena sativa*) are descended from *Avena fatua*, a common wild oat. Some of the varieties grown in southern Europe are descended from *A. sterilis*, others from *A. strigosa* and *A. barbata*. Oats cultivated in northern Africa, Abyssinia, Asia Minor, and Mesopotamia are closely related to the other Mediterranean oats. The varieties of naked oat have their home in or near China.

Wild Oats.

Avena fatua occurs among cultivated oats, and it may increase and become a weed if the seed grain is not cleaned and selected. It grows vigorously in the field when finer varieties are checked by weather. The plant is thin-strawed and scanty, though it frequently grows taller than the cultivated variety. The ear is large but sparse, and bears clusters of two or three flowers with grain. The grain ripens quickly and is easily shaken from the ear, so that a number of grains may be left on the land after harvest. Each grain in a cluster bears a strong, dark, twisted awn arising from the middle of the chaff; cultivated oats have either no awn or only one which arises on the outer chaff of the lower floret, the inner or second

Spikelet of Wild Oat; each grain is awned. A Grain with long awn on outer chaff, and numerous hairs.

grain being awnless. The presence of a second awn in the clusters of some uncommon varieties suggests that they are more nearly related to the wild oat. The grain-chaffs of the wild oat are long, pointed, and bear grey or reddish hairs round the base of the chaffs, from the base upwards to the insertion of the awn, and on the rachilla or slender stalk joining the lower grain to the upper. Cultivated oats have few or no hairs on the chaff. The naked grain or kernel is more hairy in the wild oat than in cultivated. The base of the ripe grain has a horse-shoe shaped mark. A number of forms of wild oat have been recognized, some of them showing resemblances to cultivated oats, and by continuous selection from these, new races of oats have been obtained. The reverse process of atavism has been observed at the Svalöf Experimental Station. Individual plants in several of the pedigree races showed reversion as regards occurrence of hairs and awns, and these plants, when isolated, yielded amongst their progeny individuals scarcely to be distinguished from the wild oat.

Other wild species of oats have the following characteristics:

Avena sterilis has long chaffs up to 1½ inches long, the base bearing long, reddish-brown hairs; each spikelet has two, three, or four flowers, and the grain is not so loose as in *A. fatua*; the awns are long, and by twisting when dry and untwisting when damp, they cause the grain to move, hence the name " animated or fly oat ".

Avena strigosa, the bristle oat, has three awns on each floret, one the real dorsal awn, the other two, shorter bristles on the tip of the flowering glume enclosing the grain; the base of the grain has few hairs; the ear is somewhat one-sided. Straw thin and short.

Avena barbata, a Mediterranean form, resembles *A. strigosa*, but the grain axis is more velvety.

Avena nuda, the naked oat, is a cultivated species with five or more florets and grains forming a long spikelet, so that the upper grains are visible above the large, loose, barren glume; the grain is so loosely held in the chaffs that on threshing it falls out, as in common wheat.

The species name *Avena brevis* has been given to the Short or Grey Oat, still to be found in cultivation in northern Scotland; it has one-sided ears with one or two grains in each cluster, and each grain is awned, but the brownish or greyish grains are shorter and plumper than either *A. fatua* or *A. strigosa*.

Botanical Characters.

The varieties or races of cultivated oats may be distinguished to some extent by external characters, such as mode of growth, form of ear, colour, grain-chaffs, shape of the grain and kernel, and the occurrence of awns. None of these can be used by itself for classifying the numerous varieties,

but some description of them is necessary to understand the grouping suggested later.

Mode of Growth.—The oat plant arises from the grain, which on germinating gives off first a set of three to seven seedling roots, then a shoot. The first appearance of the shoot above ground is a white sheath with no leaf-blade, then follow leaves with blades and sheaths. The earlier leaves arise almost at the same level near the surface of the soil, but later the stem elongates into a straw bearing about eight leaves, each with a sheath which arises from a node or joint. At the base of the straw the nodes are closely crowded, and it is from these lower nodes that buds arise which form tillers or lateral shoots; the upper nodes rarely tiller unless the straw is laid or flattened down by weather. The growth of each shoot terminates in a single ear, but occasionally one or two small additional ears may be seen arising from the higher nodes on the straw. The number of nodes is fairly constant, and the length of a straw depends on the amount of lengthening between each node.

Root Formation.—The growth of the first group of seedling roots is limited. Examination of an oat plant, after a few leaves are formed, will show that a new set of roots has arisen from one or more of the lower nodes at the base of the first shoot; these become the main feeders of the plant, and the first seedling roots go out of action. In a shallow or unfavourable soil the nodal roots are nearer the surface, but in a deep, tilthy soil they extend deeper. Uneven depth of sowing is regulated by the nodal roots, since the oat plant can adjust root formation and find suitable soil conditions.

Tillering.—The first tillers arise from the lower nodes of the first seedling shoot, below or near the surface of the soil. Later each tiller-shoot may give off tillers from its lower nodes, and thus a tuft of shoots is produced from a single grain. The tillers arise in succession, so that the ears do not all ripen at the same time. The first shoot and one or two of the earlier tillers produce the taller, stronger ears which ripen first; the younger tillers are generally shorter and later. When the first shoots are destroyed by frit-fly or other agents, growth of the plant is continued by tiller-formation, but the final result is generally a tuft of small tillers, green and deficient in ear at harvest.

The varieties of oats differ considerably in tillering power. Many of the older north-country varieties, such as Sandy, tiller abundantly, hence they are hardy but late in ripening, good straw-producers but often deficient in grain. The group of Potato oats, and most winter oats, also tiller abundantly, but yield more grain. The majority of the more recent varieties are grain-producers, and under ordinary cultivation each plant bears three or four ears, which receive the whole food supply, carry more grain, and ripen more equally. The straw-producing varieties yield a finer straw more suitable for stock wintered on straw and turnips,

as in the northern counties. The grain-producing varieties tend to have a coarser straw, especially the Tartarian selections and hybrids, but several, including Waverley, Yielder, Record, Victory, and Crown, yield a considerable amount of useful straw.

Shape of Ear.—An ear or panicle of oats consists of an erect central axis bearing numerous branches of different lengths. All the branches except the uppermost, if traced to where they arise from the axis, will be found to belong to one of three or four whorls; the lowest whorl has the largest number, and the longer branches, the middle one is intermediate, and the upper whorl has only a few short branches. This arrangement produces a pyramidal ear broadest at the base and tapering upwards. The upper part or tassel of the ear may consist of branches grouped closely together, hence the ear has a compact appearance, as in most of the newer varieties. In many old-fashioned oats the tassel is long drawn out, and gives the ear a lean, meagre appearance.

The shape of an oat ear depends considerably on the angle taken up by the branches. Most of the favourite varieties have stiff upstanding branches, so that the ear looks dense and compact. The Tartarian varieties have the branches almost parallel to the axis, and, as they mainly grow out on one side, the ear is dense and one-sided. Many older varieties have the branches standing out at right angles or even drooping.

The Grain.—The oat grain after threshing still retains its covering two chaffs, the larger flowering glume with its margins enclosing the inner narrower pale. Occasionally samples are seen with a large proportion of kernels or naked grains, which may indicate a loose-chaffed variety, or it may be the result of threshing either at too high a speed or with the beaters too close together. Every sample of oats contains larger grains with longer and thicker chaffs, and smaller grains with thinner chaffs. The larger grain is the first or lower one of a spikelet, the smaller is the second, or the third in " three-pickle clusters ". When an awn is present it arises about the middle of the first grain only.

The majority of the newer oats are awnless, but there may be some grains with awns or traces of awns, and it is not easy even by careful selection to eliminate the awn entirely. Many of the older varieties have strong awns, thus resembling the wild oat.

As a rule the two or three grains in each spikelet are separated by threshing, but in the thick-skinned Tartarian varieties there is often a number of double pickles or bosom-grains. This arises when the second grain in a spikelet has a short stalk and is so close to the lower grain that the large chaff of the latter wraps round or partially encloses the second or bosom-grain. This is no advantage, because either the second grain is small, or the kernel of the first grain does not develop fully; the percentage of husk is thus increased.

Thick- and Thin-skinned Oats.—A bushel of oats consists of so

much chaff or husk, and so much grain or kernel. In thin-skinned oats the proportion of husk to kernel may be as low as 20 per cent, whereas in thick-skinned oats it may be 33 per cent by weight. That is, every sample of oats includes from one-fifth to one-third of its weight of husk. Kernel is much superior to husk in feeding value. An analysis which gives in the kernels, oil 7 to 8 per cent, albuminoids about 15 per cent, and fibre 2 to 3 per cent, will give in the husks about 1 per cent oil, 2 to 3 per cent albuminoids, and 30 to 35 per cent fibre. A thin-skinned oat supplies more oil and albuminoids, whereas a thick-skinned one increases the less digestible fibre. The objection of the oatmeal miller to thick-skinned oats is well known, though it is now being admitted that meal from Victory, Beseler, and similar varieties is equal to that from the best Potato oats. Recent investigations indicate that the milling qualities of oats depend not so much on thin husk but on their quality and suitableness for the milling machinery.

The proportion of husk to kernel varies considerably, even for the same variety. This is mainly due to uneven ripening, the result of season. A plump, evenly filled sample will give less husk than a sample with starved, poorly filled grains, because in the latter it is the kernels which are affected more than the chaff. Allowing for seasonal differences, there is, however, a marked difference in the varieties. The largest proportion of husk occurs in Tartarian oats and hybrids or selections from them; as a rule these approach 30 per cent. A percentage of husk less than 25 per cent is general in well-ripened samples of classes 2 (Ligowo) and 3 (Potato) given below.

Colour.—The true grain or kernel varies little in colour, but the enclosing chaffs show all tints from almost white to deep black. In the case of black or brown oats the colour rarely extends to the large chaff (barren glume) enclosing the spikelet, so that the ears are not black, but yellowish or whitish in the field. If there is much dark pigment in its tissues, the chaff is deep black, but with less pigment every shade is produced, as in black, brown, dun, and grey oats. Absence of pigment gives the common whitish chaff. There is also a yellow colouring matter, and if this is present the result is a yellowish white grain (e.g. Yielder) or a deep yellow (e.g. Golden Rain).

Shape of Grain and Kernel.—A comparison of the larger or first grains in an oat sample indicates something as to the variety. Many of the older oats have a large outer chaff wrapped tightly over the inner chaff, and ending in a long point, so that the grain has a lean, lanky appearance; the kernel is slender and does not fill the upper part of the space between the chaffs. The same features may be seen in empty or blind grains of any badly ripened sample, and they reduce the bushel weight. The Potato oat has an egg-shaped kernel, broadest at the base and tapering upwards to a flat tip; the whole grain appears short, because

the chaffs end abruptly and do not extend much beyond the kernel. The Tartarian oats are larger with an egg-shaped kernel, but the plump grains taper quickly to a sharp point. The large-grained new varieties have an oblong cylindrical kernel with the tip almost as thick as the base.

Classification of Oats.

The following grouping of the better-known varieties of oats is based on characters of the ripe ear in the field, and on other features seen in the grain sample. An examination of the ears and grains themselves will probably convey the characters better than words. When varieties are placed together under one group it does not mean that they are identical, though some are hard to distinguish from each other. Within each group there may be considerable variation in shape and colour, or in qualities, such as time of ripening and yield, which cannot be recognized by mere eye-examination. In the case of older varieties there is considerable confusion in the descriptions, and, when we have grown samples supplied, more than one kind of oat has been obtained from the same packet of grain. Probably the older varieties were less true to type and not so carefully selected as the newer-named varieties from reliable sources.

1. **Tartarian or Plume Varieties.**—Ear long, narrow, one-sided, with stiff, upright, and crowded branches. Grain large and plump, generally with thick chaff. Kernel egg-shaped, broad at the base, and tapering. Tillering not usually abundant. Straw hard and stiff. Many useful and prolific varieties belong to this group, though the hard straw and thick-skinned grain are not approved of by all growers.

(*a*) *White Varieties.*—White Tartarian, introduced into England about 1780. Storm King and Tartar King, Garton hybrids resembling White Tartarian.

Yielder, Record, Hero, and Captain are Garton hybrids between Tartarian and another parent from one of the other groups; the grain is thinner in the husk than true Tartarian, and the one-sided ear is not so pronounced.

(*b*) *Black Varieties.*—Black Tartarian, introduced about 1780, has replaced most of the older varieties of dark-coloured oats. Excelsior and Rival, Garton hybrids. Black Bell I and Black Mogul, recent selections from Svalöf (Sweden), have a thinner husk and open ears. Black Bell II and III, hybrids from Svalöf.

2. **Close-eared Varieties.**—Ear dense, with stiff, ascending, high angle branches and a tendency to be one-sided, but less so than in Tartarian. Grain large and elongated, with the outer chaff either blunt or pointed, and the inner thin chaff or pale not firmly enclosed at the apex, so that the tip of the kernel is loosely held. Kernel elongated, oblong,

Close-eared type. Open-eared type. Tartarian type.

TYPES OF OATS

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and cylindrical (not egg-shaped). Rarely any awns or hairs. Tillering better than Tartarian, but not usually so abundant as in Potato oats.

This group contains most of the heavy-grain oats of the present time. They produce a useful straw, and are gradually taking the place of the older straw-producing oats belonging to Group 3.

The close-eared oats can be further subdivided:

(*a*) *Probsteier or Abundance Varieties.*—Grain blunt-tipped, because the outer chaff has a broad tip as if torn across just above the kernel. Probsteier, an old variety long grown in the better districts of Sweden, Denmark, and the Baltic, is the parent race from which most of the following have been selected:

Ligowo, an early selection from Probsteier by Vilmorin, Paris. Swedish White, Waterloo, and Clydesdale, old British varieties from which the writer has selected blunt-grained races. Abundance, a well-known Garton hybrid raised from two Probsteier parents, White Swedish and White August. Newmarket, Webb's selection. Banner, Mounted Police, and Thousand Dollar, American selections productive in trials in Britain. Victory, Crown, and Golden Rain (Yellow), Svalöf selections from Probsteier and now being tested in Britain. Beseler I, II, III, German selections from Probsteier; Beseler II or Beseler's Prolific has been productive in Britain. Danish Island and Grenaa, Danish selections.

(*b*) *Leader Varieties.*—Grain like that of (*a*), but pointed because the outer or thicker chaff ends in a long point beyond the kernel. When the kernel is plump the chaffs are loose at the tip, but with lean kernels the inner chaff is enclosed in the pointed outer chaff. Leader, Waverley, and Goldfinder (yellow) are Garton hybrids. Sixty-day oat, an early yellowish oat, was introduced into the United States about twenty years ago from Podolia (South Russia), and from it several white and yellow varieties have been selected in the United States and Canada. Wide-awake, an older American variety, has proved productive in Scottish trials. Joanette, a black French variety improved in Canada.

3. **Potato Oat Varieties.**—Ear open and pyramidal, branching equally all round; branches wide or flat. Grain small, short, and plump, thin-skinned; the outer chaff blunt or short-pointed, the inner chaff not firmly held at the apex. Kernel, loose, egg-shaped, tapering upwards to a flat tip. Awns may be present in inferior samples. Tillering abundant, which tends to unripeness of late-formed tillers, hence greenness at harvest. This group includes the more characteristic northern varieties, hardy in adverse seasons, and straw-producing.

Potato oat, selected in 1788 from a field of oats in Cumberland, much cultivated in Scotland, and parent of many selections. Early Angus, old variety in cultivation before Potato oat. Kildrummy and Dyock, old selections in cultivation before 1852. Hopetoun, Shirreff, and Early

Fellow, the more popular selections of Patrick Shirreff, made between 1824 and 1866 either from Potato or Early Angus. Sandy, selection from Potato in 1824, still cultivated in the north. Mesdag (black), old Dutch variety improved by Vilmorin. Hamilton, Longhoughton, and Castleton, newer selections from Potato. Dala, Svalöf selection. Siberian, recently improved in Canada, Russian origin.

4. **Open-eared Varieties.**—Ear open and pyramidal, branches somewhat flat or drooping. Grain long and pointed, with outer chaff closely folded over the inner one. Kernel cylindrical, and not long enough to fill the space between the chaffs. Awns and hairs often present. Tillers abundant. Grain yield deficient. The following varieties appear to be of this type or the preceding one: White Poland, Late Angus, Blainslie, and Barbachlaw, all white varieties, in cultivation before or about 1800. Providence or Berlie, Tam Finlay or Old Poland, Friesland or Dutch, in cultivation about 1852. Grey Angus, with whitish blue grain. Dun and Winter Dun, brownish grain; various selections grown as winter oats in England. Etampes, black French variety used as parent for recent selections in Canada.

THE OAT CROP

By PRINCIPAL PATERSON, B.Sc., N.D.A.(Hons.)

ACREAGE UNDER OATS

From the point of view of acreage, the oat crop is by far the most important of the cereals grown in the United Kingdom, the area under this crop being actually greater than that of wheat and barley taken together.

The table on the following page gives the area under oats in 1921, and also shows the relative distribution of the three cereal crops, oats, wheat, and barley, at intervals of five years for the period 1900 to 1920. The corresponding figures for the years 1914 and 1918 have also been given, for the purpose of showing to what extent the acreage under oats and other cereals was affected by war conditions.

The acreages given in the table emphasize the great importance of the oat crop in Scotland and Ireland, the area under oats in these two countries being about four times as much as the combined areas under wheat and barley. In England, on the other hand, wheat is relatively much more widely grown, and even in 1914, and prior to the Great War, the area under wheat was slightly greater than that under oats. If,

AREA UNDER OATS, WHEAT, AND BARLEY

	England.	Wales.	Scotland.	Ireland.	United Kingdom.
	Acres.	Acres.	Acres.	Acres.	Acres.
1921, Oats ..	1,952,063	215,358	1,011,615	1,254,000	4,412,036
1920 Oats ..	2,016,531	249,093	1,032,198	1,332,050	4,629,872
1920 Wheat..	1,824,037	50,548	54,359	50,252	1,979,196
1920 Barley..	1,537,735	99,225	204,369	206,888	2,048,217
1918 Oats ..	2,414,559	365,502	1,243,823	1,579,535	5,603,421
1918 Wheat..	2,460,695	95,966	79,062	157,326	2,793,049
1918 Barley..	1,394,861	105,948	152,835	184,712	1,838,356
1915 Oats ..	1,888,568	199,479	982,600	1,088,664	4,182,296
1915 Wheat..	2,121,519	48,651	76,654	86,530	2,335,091
1915 Barley..	1,151,544	80,178	149,346	141,586	1,524,316
1914 Oats ..	1,730,091	199,535	919,580	1,028,758	3,877,964
1914 Wheat..	1,770,470	37,028	60,521	36,913	1,905,933
1914 Barley..	1,420,346	84,425	194,109	172,289	1,873,280
1910 Oats ..	1,857,731	205,093	958,150	1,073,690	4,094,664
1910 Wheat..	1,716,629	39,428	52,797	47,631	1,856,485
1910 Barley..	1,449,492	87,569	191,620	168,008	1,896,689
1905 Oats ..	1,880,475	207,929	962,972	1,066,806	4,118,182
1905 Wheat..	1,704,281	43,891	48,638	37,860	1,834,670
1905 Barley..	1,410,287	91,243	212,134	154,645	1,868,309
1900 Oats ..	1,860,513	216,447	949,128	1,105,050	4,131,138
1900 Wheat..	1,744,556	51,654	48,832	53,821	1,898,863
1900 Barley..	1,645,022	105,048	240,195	174,173	2,164,438

however, we take into account the acreage under oats, also the average yield per acre and the value of the produce, the oat crop is far and away the most important cereal crop cultivated in the United Kingdom. At the same time it should be borne in mind that though the acreage under oats may appear extensive compared with the acreage under the other cereals, it nevertheless constitutes a relatively small proportion of the world's acreage, being as a rule just about one-twelfth of that of Russia, one-tenth of that of the United States, one-third of that of Canada, and one-half of that of Germany or of France.

The figures given in the table also show the greatly increased acreage under oats in 1918, when more than five and a half million acres were under this crop in the United Kingdom, as compared with little more than four million acres in 1914, at which time cropping had not been

affected by war conditions; they also indicate the falling off in 1920 as compared with 1918.

PROGRESS IN CULTIVATION

The cultivation of the oat did not make very rapid progress in this country, and the varieties grown in earlier times produced, in comparison with those of the present day, very light inferior grain. In the Middle Ages the Naked oat appears to have been the variety most widely grown in England, and it was still grown to a considerable extent in northern Britain even in the beginning of the eighteenth century. A step forward was effected at that period through the introduction of the Poland oat into England, and in the latter half of the eighteenth century Black Tartarian and White Tartarian oats made their appearance. These varieties soon became popular, and their cultivation rapidly extended. The greatest advance, however, really followed the discovery and introduction into cultivation of the Potato oat in the last quarter of the eighteenth century, and this variety was widely cultivated during the whole of the nineteenth century and is still a favourite variety in many districts. The introduction of the Sandy oat early in the nineteenth century marked a further development, as that variety was found to be very suitable for poor soils and exposed situations, and on such could be relied upon to give a much better return than that obtained from the Potato oat.

About the same time Hopetoun—a selection from Potato—was introduced by Shirreff, of Haddington, and numerous other varieties, such as Angus, Berlie, Blainslie, Dun, and Friesland, appear to have been well known and fairly widely grown.

Later in the nineteenth century strains of Black oats were selected by Major Hallett and by Bennet, who were amongst the most successful of the selectors at that time.

The year 1892 saw a very great development, and one which has had a most marked effect on oat cultivation in this country. Up to that time the varieties introduced had been for the most part selections from other oats, but in that year Mr. John Garton, of the firm of Garton Brothers (now Gartons, Ltd.), introduced the Abundance oat, the first variety produced by crossing selected varieties. The Abundance proved to be an early prolific oat of good quality. Its cultivation rapidly extended, and it was very soon one of the most prominent of the varieties grown in England. Since that date the same firm has by similar methods introduced numerous other valuable varieties, and each season still brings as a rule another promising one.

Other noteworthy introductions in the very end of the nineteenth century and early in the twentieth century were those by Wright (then Principal of the West of Scotland Agricultural College), who introduced

varieties from other countries, some of which are still widely grown, and those in recent years from the Svalöf plant-breeding station, Sweden. Victory, one of the Svalöf varieties, is at the present day fully the most popular and most widely grown oat on the better soils in this country.

The introduction of new and prolific varieties of oats is receiving more attention than ever before, and there is no reason to suppose that the possibilities in that connection have been exhausted. We have in one sense travelled a long way, but we still have an open road before us, and great are the possibilities of further improvement.

VARIETIES OF OATS

Varieties of cultivated oats are legion in number and still continue to become more numerous, as new varieties are always being raised and introduced into general cultivation. Many of the varieties differ from each other in very small degree, but there are other varieties in which the differences are very marked. The following are amongst the more important features in which there is considerable variation:

1. **Colour of Grain.**—The majority of the varieties grown produce grain that is white in colour. The next most numerous class have yellowish grain, but black is also very common. In addition, a few varieties produce grain that is somewhat red or brown, and a still smaller number have greyish coloured grain.

2. **Shape of Grain.**—There is also considerable variation here, for certain varieties produce grain of a short, thick, plump type, while other varieties produce grain that is much longer and thinner in type. This variation in type of grain has given rise to the simple classification of Short oats and Long oats adopted by some writers.

Another classification which met with a good deal of favour included an intermediate class, the terms applied being (*a*) oviform or egg-shaped oats, when the grain was short and plump; (*b*) coniform, when the grain was medium; and (*c*) fusiform, when the grain was long and thin in type. Varieties of oats were placed in one or other of these classes according to the kind of grain they produced.

3. **Type of Ear.**—This feature is one in which there is considerable variation, and readily suggests another method of classification. Some varieties of oats have an open spreading panicle, the grain being carried more or less regularly all round; some have a one-sided panicle, the grain being carried on one side and giving a somewhat banner-shaped appearance; and some are kind of intermediate.

4. **Length, Type, and Standing Power of Straw.**—Some varieties have long straw; others again produce straw that is short or medium in length. Some varieties have very fine thin straw, while others have stronger and stouter straw.

This feature, unlike the preceding ones, is really a feature of definite agricultural value and therefore of much greater importance. From the farmer's point of view what is wanted in this respect is straw of good feeding value (good fodder), which will bulk well, stand up well, and at the same time carry a heavy weight of grain. There is, however, great difficulty in combining all these good features in a single variety.

5. **Earliness.**—This, like the last, is a feature of very great importance. Some varieties ripen as much as three weeks before others, even though sown at the same time and under similar conditions, and, in late districts especially, early ripening oats are very much to be preferred, as with these there is a much better chance of securing the crop in good condition.

6. **Yield per Acre.**—As oats are grown for their grain and straw, it seems reasonable to suggest that yield per acre would form a satisfactory basis for classification, particularly as there is considerable variation in the yielding powers of different varieties.

In connection with this feature, oats, according to their yield of grain or straw, fall naturally into two classes, which are on the whole fairly distinct from each other. Class 1 contains the varieties of oats which are capable under favourable conditions of giving a very heavy yield of grain per acre, the total weight of which approximates to or even surpasses the total weight of straw. Class 2, on the other hand, includes the oats which, while not quite equal to the varieties in Class 1 as regards yield of grain, are on the whole superior as regards yield of straw, the total weight per acre being generally considerably greater than the yield of grain.

Varieties in Class 1 might appropriately be termed grain producers, and those in Class 2 straw producers.

Adopting this classification, we find that almost all the more recently introduced varieties fall to be classed as grain producers, but that the great majority of the older varieties of oats come under the category of straw producers.

GRAIN PRODUCERS

This class includes such varieties as Sir Douglas Haig, Captain, Leader, Record, Yielder, Abundance, Tartar King, Storm King, Waverley, Supreme, Pioneer (all introduced by Gartons). Victory, Crown, Black Bell, Golden Rain (Svalöf varieties). Newmarket and White Horse (selected and introduced by Webb). Beseler, Wideawake, Mounted Police, Banner (introduced by Wright). Also Black Tartarian and many other varieties.

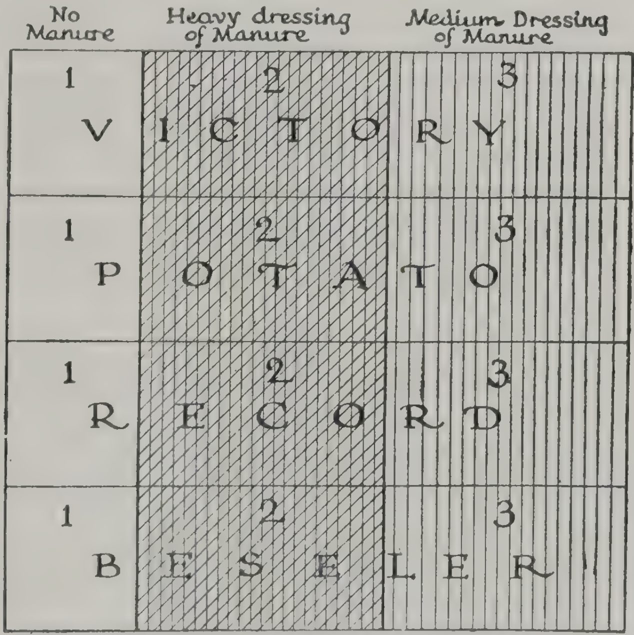
These grain producers under suitable conditions are capable of giving a much heavier yield of grain per acre on the better soils than can be obtained from the straw producers; but on the average they give rather less straw.

As they do not succeed equally well under all conditions, a good deal of discretion must be exercised in selecting varieties for different conditions if the best results are to be obtained. In the first place, they are best adapted for the better classes of soils, and when grown on these the great majority of the varieties of the grain-producing type are capable of giving a very heavy yield of grain. On the medium soils many of them also do well, provided the scheme of manuring is adequate, particularly Record, Victory, Crown, Abundance, Yielder, Mounted Police, Beseler, Wideawake, and Leader. Black Tartarian is specially suited for the mossy or peaty soils.

On the lighter and poorer soils generally, the return from these varieties is rather disappointing unless they are fully and judiciously manured; but as soil deficiency can to a very great extent be made good by manuring, the adoption of that practice makes it possible to grow many of the grain-producing varieties successfully, even on the poorer soils. Under such conditions varieties like Record, Victory, Beseler, and Yielder are amongst the most suitable to sow.

The following results are typical of many others obtained in experiments designed not only to demonstrate the benefits that accrue from manuring in general, but also to show that while grain producers, in the absence of manure, may not be superior on medium and poorer soils to varieties of the straw-producing class, they may prove to be very much superior where well-balanced artificial manures are applied.

Ten acres of somewhat poor, light, but uniform land in the centre of a 40-acre field in Wigtownshire were selected. This area was cropped and manured according to the following plan:



In this plan the four plots marked 1 were each half an acre in extent. The four plots marked 2 were each an acre in extent, and the four marked 3 also an acre in extent, making up a total of 10 acres in all.

In every case plot 1 got no manure.

Plot 2 got a dressing of $\left\{\begin{array}{l}\text{3 cwt. superphosphate,}\\ \text{1 ,, sulphate of ammonia,}\\ 1\frac{1}{2}\text{ ,, common salt.}\end{array}\right.$

And plot 3 a dressing of $\left\{\begin{array}{l}\text{2 cwt. superphosphate,}\\ \frac{5}{8}\text{ ,, sulphate of ammonia,}\\ \text{1 ,, common salt.}\end{array}\right.$

Owing to the Great War potash was not available, and salt was used as a substitute.

The manures for the different sections were mixed together prior to sowing, and were harrowed in along with the seed.

The yields obtained per acre on the different plots were as follows:

Variety of Oats grown.	Plot 1.			Plot 2.			Plot 3.		
	Grain.	Straw.		Grain.	Straw.		Grain.	Straw.	
	Bus. (40 lb.)	Cwt.	Lb.	Bus. (40 lb.)	Cwt.	Lb.	Bus. (40 lb.)	Cwt.	Lb.
Victory ..	49	16	90	$70\frac{1}{2}$	28	54	$70\frac{1}{2}$	25	95
Potato ..	$49\frac{3}{4}$	22	56	$56\frac{1}{4}$	28	56	$55\frac{3}{4}$	26	82
Record ..	$57\frac{1}{4}$	23	54	$70\frac{3}{4}$	20	37	$68\frac{1}{4}$	26	53
Beseler ..	$47\frac{1}{2}$	19	40	$71\frac{1}{4}$	26	78	$64\frac{1}{2}$	22	103

These results are typical of many others obtained at demonstration and experimental centres, and they go to prove that *very often it is the manuring more than the class of land that determines the suitability of the variety for the purpose in view.*

The yield of grain given is in every case the total yield and includes the light grain. That makes it rather higher per acre than otherwise would have been the case, but it is quite clear that, on the unmanured section, the only variety in any way superior to Potato was Record. On the manured sections, however, all the grain producers were decidedly superior to Potato.

The above results also bring out clearly another very important feature, viz. that grain producers are capable of responding to manuring to a much greater extent than straw producers, as their natural limit, as regards yield, is evidently very much higher. This is a feature of very special importance and one which should never be overlooked.

In addition to the normal yield of grain being heavier on good soils with these grain producers, and the response to manuring greater on soils where manure is required, there are several other features in which

certain of the varieties in this class show marked superiority over the straw producers. For example, they are not so liable to lodge; they are freer from smut; they are rather better drought resisters; and are more suitable for sowing out with grass and clover seeds.

As regards standing power, this is a most important feature when a big acreage has to be cut in the minimum of time and with the minimum of labour. A crop that has gone down badly is costly and laborious to reap, and absorbs much time in a busy harvest season when every day counts for a great deal, but a crop which is standing can be very quickly dealt with. There are, of course, some varieties which stand up very much better than others, and the following may be mentioned as particularly good standing varieties, viz. Record, Yielder, Leader, Captain, Storm King, and Sir Douglas Haig.

In regard to freedom from smut, as this feature is taken up later under SELECTION AND TREATMENT OF SEED, no further reference to it is required here, except to affirm the superiority of grain producers in that respect.

The capacity to withstand drought is a very important one. The yield always suffers very materially in a dry year, but experiments conducted in the South of Scotland during the dry season of 1919 indicated very clearly that many of the grain producers do not suffer to quite the same extent from the dry weather as some varieties belonging to the straw-producing class. This is contrary to the belief that prevails, and it is a feature which should be further investigated.

The superiority of the grain producers for sowing with grass and clover or other seeds is undoubted. They stand up better, so that there is less risk of the seeds being smothered out by the crop lodging. They do not tiller or "stool" out so freely; consequently they make very much better nurse crops, and the young plants get more room, more light and air, and a better chance to get fully established.

Amongst these grain producers there is very great variation in the time of ripening. Some varieties have a relatively short growing season and ripen very rapidly, others again require more time to develop and mature. Varieties of oats that ripen early are often invaluable in the later districts, but they are much less suitable for the earlier districts or for soils that tend to become very dry, as under such conditions the ripening process is often hastened unduly, and the grain does not get the same opportunity to fill; consequently when threshed the yield is disappointing and there is a big proportion of light grain. In such circumstances, medium and slower maturing varieties are much superior to early ripening varieties.

Amongst the grain producers fully the earliest ripening varieties are, Orion, Captain, Yielder, Golden Rain, Storm King, Waterloo, and Superb. Varieties such as Abundance, Leader, Record, Crown, Victory

are intermediate in time of ripening. Wideawake, Goldfinder, and Black Tartarian are often amongst the last of the grain producers to ripen.

The following table, taken from a Bulletin issued by the Agricultural Department of the University College of North Wales, Bangor, is of interest in this connection, and gives an indication of the time required for growth and ripening under the conditions that prevail there:

1920.		1921.	
Classification of Varieties in Order of Ripening.	Days from Sowing to Ripening.	Classification of Varieties in Order of Ripening.	Days from Sowing to Ripening.
Yielder	127	Captain	103
Golden Rain	128	Golden Rain	105
Captain	128	Yielder	106
Tartar King	129	Record (new)	107
Record (new)	131	Abundance	108
Record (home grown)	131	Victory	109
Wideawake	132	Crown	109
Hero	134	Bountiful	110
Leader	134	Beseler's Prolific	111
Victory (home grown)	135	Wideawake	111
Supreme	136	Leader	112
Sir Douglas Haig	137	Waterloo	114
Beseler's Prolific	138	Sir Douglas Haig	114
Victory (new)	138	Record (home grown)	114
Bountiful	140	Yellow Naasgard	115
Guinea Gold	140	Goldfinder	115
Yellow Poland	141	Black Tartarian	117
Goldfinder	143		

STRAW PRODUCERS

This class includes practically all of the older varieties of oats, the chief difference from the grain producers being that the varieties in this group are not capable of giving under favourable conditions such a high yield of grain. The actual difference in yield varies according to circumstances; it may be no more than 5 bushels, or as much as 25 bushels per acre, but 10 to 15 bushels represents approximately the average difference. They are, however, superior as regards yield of straw, and are found in general to be more reliable for growth in unfavourable conditions. As examples of varieties in this class the following may be mentioned: Potato (also Hamilton, Early Fellow, and Longhoughton, which are selections from Potato), Sandy, Providence, Blainslie, Tam Finlay, Berlie,

Clemrethery, Grey Winter, Black Winter, Dun, Ceirch du Bach, and Radnorshire Sprig.

With certain of the grain and straw producers, the line of cleavage is not very distinct, but with the majority of the varieties there is a very marked difference.

As already indicated, these straw producers are more reliable and give a surer return under certain circumstances; moreover, they are decidedly superior for special purposes.

Whenever a tough, fibrous turf has to be dealt with, as is often the case when land has been down to grass for several years, varieties such as Sandy, Potato, and Providence are likely to give a better return than varieties of the grain-producing type.

Again we find that varieties in the class under consideration are, on the whole, hardier than grain producers; consequently under unfavourable climatic conditions, as in high exposed situations, they give a better account of themselves, though under similar conditions as regards soil and manure they might, in a more favourable climate, prove very much inferior. Climate is, undoubtedly, a very potent factor in determining whether a certain variety may be successfully grown or not.

Again, straw producers not only give more straw but straw which is finer in quality, and on many dairy farms, where special importance is attached to the production of fodder, they are preferred to the grain producers for that reason. It has, however, yet to be demonstrated that the actual feeding value of the straw is, weight for weight, higher than that from many of the grain producers. At the same time many of the varieties in the latter group do produce straw of a coarser and less palatable type, but, after all, grain production is in the great majority of cases the chief consideration.

When the land for oats is foul and a thick heavy crop is desired to keep down weeds, varieties of the straw-producing type are very much more suitable than grain producers, as the former tiller out more, give a thicker growth, and consequently have a more pronounced effect in smothering out or preventing weeds in the soil from developing. These varieties are, however, more liable to lodge, and though a crop that goes down fairly early has a very salutary effect on foul land, and generally completely smothers out the weeds, the reduction in the yield and quality of the produce and the increased costs of harvesting are so great that no farmer wants to clean his land by that method.

Straw producers, though they do not give the same yield of grain per acre, are slightly superior in regard to the return in meal per bushel of oats, but milling properties of oats is dealt with separately.

Sometimes a mixture of two varieties, a grain producer and a straw producer, is sown, and, provided two varieties are selected which ripen near the same time, there are under certain circumstances slight advan-

tages. As a rule it is a method of increasing the yield of straw compared with what would be obtained from a grain producer by itself. It may also be adopted for the purpose of getting a better standing crop, the inclusion of Record, Yielder, Leader, and similar stiff-strawed varieties having quite a marked effect on the standing power.

As a rule the yields of grain and straw from a mixture of two varieties is intermediate to the yields from the two varieties when sown separately under similar conditions, and this view is confirmed by the results obtained from experiments carried out by the West of Scotland Agricultural College during seasons 1912, 1913, and 1914, and referred to in the *Scottish Journal of Agriculture* (1918). These tests were carried out at twenty-eight different centres in the south-west of Scotland; the varieties sown were Beseler and Potato; the plots were each one-tenth of an acre in extent, and were seeded at the uniform rate of 3,000,000 seeds per acre. The plots were manured exactly alike, a uniform dressing being applied at the rate per acre of 2 cwt. superphosphate, 2 cwt. kainit, and $\frac{3}{4}$ cwt. sulphate of ammonia. The mixture of manures was applied at the time of seeding, and harrowed in along with the seed. The average of the yields obtained for the three seasons was as follows:

	Grain.	Straw.
Beseler	64 bus.	$36\frac{1}{2}$ cwt.
Beseler and Potato ..	$59\frac{1}{2}$ "	$38\frac{1}{4}$ "
Potato	$53\frac{3}{4}$ "	40 "

These results give an indication as to what may be expected when a mixture of two varieties is sown under average conditions.

NOTES ON VARIETIES

1. GRAIN PRODUCERS

A.—ABUNDANCE GROUP.

Abundance.—Introduced by Gartons in 1892. Raised by crossing White Swedish and White August, both of which belong to the Probsteir type. Probsteir, from which many varieties have been obtained, is an old variety extensively grown in Germany and neighbouring countries.

Characteristics of Abundance: a white oat with large-sized grain and thin husk. Grain of good milling quality. Straw long, somewhat coarse, and inclined to lodge on good soils. Intermediate in time of ripening, being a few days later than Yielder. Open panicle; spikelets two-grained; threes frequently occur.

The following varieties belong to this group: Beselers I; Beselers II (B. Prolific); Beselers III; Newmarket, Thousand Dollar, Mounted Police, Crown, Danish Island, Pilot, White Waterloo, Giant Eliza.

Other varieties similar but not necessarily related to Abundance are: Banner, Scottish Triumph, Stable King, Superb, Waverley, White Horse, Wide Awake.

The most important of the above varieties are briefly described below.

Banner.—Brought from America in 1899 by Wright. Not so popular in this country

as formerly, but still grown to some extent, especially on the better class of soils in early districts. Rather later than Abundance in ripening.

Beseler's Prolific.—Introduced by Wright from Germany in 1901. Later than Abundance. Suits a wide range of soils.

Crown.—A Svalöf variety selected from Probsteir. Recently introduced. Grain, longer and thinner than that of Abundance. Straw long, of fairly good standing power, and above the average in quality. Medium late in ripening. One of heaviest yielding varieties and suits a wide range of soils.

Mounted Police.—A Canadian variety introduced in 1899 by Wright. Not grown now to any extent.

Newmarket.—Raised by Webb and put on the market in 1895. A prolific variety fairly widely grown in England and in parts of Scotland.

Superb.—A cross between Supreme and Waverley. Introduced by Gartons in 1922. Grain white, short, plump, with thin husk; straw short, strong. Ripens early.

Waverley.—Introduced by Gartons in 1900. Raised from Potato, Naked Oat of China, White Tartarian, and Yellow Flanders. Grain large and plump with thin husk. Fairly extensively grown in England on medium and poor soils.

White Horse.—Put on the market by Webb in 1905. Suits rich soils.

B.—VICTORY GROUP.

Victory.—Produced at the plant-breeding station at Svalöf from the old variety Milton. Resembles in many respects the varieties of the Abundance group and is by some authorities included in that group.

Characteristics.—Grain yellowish white, smooth and shiny, plump, of good size and mills well. Straw moderately long, stiff, stands up well and of better feeding quality than Abundance. Panicle open. Spikelets short and broad with two or three well developed grains. Considerably later in ripening than Abundance. Well suited for good fertile soils. One of the most widely grown and most productive varieties at the present day.

Other varieties in this group include Ligowo, King, and Golden Rain.

Ligowo.—An early introduction from Svalöf. Not widely grown.

King.—Introduced from Svalöf in 1923. Obtained by crossing Victory and Danish Yellow Naesgaard. Claimed to be superior to Victory in grain yield and in standing power.

Golden Rain.—Also produced at Svalöf and selected from Milton. Grain of slightly yellowish tinge, rather small but plump, and of good quality. Straw stiff and stands well. Ripens early and suits soils of poorer type.

C.—YIELDER GROUP.

The following varieties were all raised by Gartons, and while they have many points in common, yet are distinct: Leader, Captain, Yielder, Hero, and Record. As arranged, these varieties are in descending order of glume length. The grains in all cases are large, with thick husks and inclined to coarseness. Doubles frequently occur.[1] With the exception of Leader, the spikelets are generally two-grained. Leader on the other hand commonly has three to five grains per spikelet.

Leader.—Raised from Abundance, Waverley, and Naked Oat of China, and introduced into commerce in 1913. A white oat with a sided ear. Like the Chinese Naked Oat it is characterized by the third, fourth, and fifth grains when present, projecting beyond the glumes. Grain large and very coarse. Straw long and of poor feeding value. Intermediate in time of ripening.

Captain.—Introduced in 1919 and bred from Waverley, Potato, and Yielder. A white oat with a compact sided ear. Grain inclined to be long and thin. Straw of medium length, coarse and with a false node of some distance below the ear. Early ripening and suited to good soils in late districts. New Harvester (Webb) is similar to Captain.

[1] The first grain is barren and represented by its husk which encloses more or less completely the second grain

Yielder.—Put on the market in 1909. Produced by crossing Waverley and Tartar King. Ear, open with a false node some distance below in well developed specimens. Straw thick, strong, and stands well. Early ripening—several days earlier than Abundance. Suits late districts and heavy soils in good condition.

Hero.—Introduced in 1916. Obtained by crossing Record, Abundance, and Naked Oat of China. Panicle somewhat one-sided. Ripens rather late and sheds readily at harvest.

Record.—Introduced in 1911. Got by crossing Storm King and Abundance. A white oat resembling to some extent the varieties of the Abundance Group. Ear open. Grain plump with a slightly upturned and open tip. Straw fairly long, stiff, and stands well. Ripens about the same time as Victory. One of the best varieties for soils in good condition.

Other varieties bred by Gartons that can be considered in this group are Tartar King, Gold Finder, Storm King, and Marvellous. Owing to the coarseness of the grain and straw, these varieties, with the exception of Marvellous, although useful in certain circumstances are not generally favoured at the present day.

Tartar King.—Produced in 1899 by crossing Black Tartarian, White Tartarian, and White Canadian. Grain white. Many doubles occur. Straw long and stiff. Ear sided, compact, and usually with a false node. Spikelets generally two-grained. Suits soil in good condition. Medium early in ripening.

Gold Finder.—A golden yellow oat introduced in 1901. Raised from crossing White Canadian, Yellow Poland, and White Winter. Grain large and long. A hardy variety doing fairly well on the poorer soils, but late in ripening.

Storm King.—A white oat put on the market in 1902, and got by crossing Abundance, White Tartarian, and Scotch Potato. Ear partially sided and compact, with false node below. Not widely grown.

Marvellous.—Raised by Gartons from Wild Oat, Grey Winter, and Gold Finder, and put on the market in 1921. Grain white, long, and broad. Straw long and strong, and rather coarse. Ear sided and compact with three or more grains per spikelet. A winter variety, but not particularly hardy and only suited to winter sowing on good soils under favourable climatic conditions.

D.—BLACK TARTARIAN GROUP.

Black Tartarian, Supreme, and Sir Douglas Haig are the varieties falling within this group. They are the most productive and most extensively grown spring-sown black oats. A point in common is the possession of a false node beneath the ears of well grown specimens.

Black Tartarian.—A very old oat introduced from the south-east of Europe about the middle of the eighteenth century. Ear sided and compact. Grain dark reddish brown to black, of medium size and rather thin. Straw long, stiff, and coarse. Extensively grown on black peaty or mossy soils because of its standing power. Ripens rather late.

Supreme.—Introduced into commerce by Gartons in 1915. A cross between Bountiful and Abundance. Grain short, plump, and deep black in colour. Straw moderately long and stiff. Ear somewhat sided with two to three grains per spikelet. Ripens medium early and is extensively grown on the better classes of oat soils as it stands and yields well.

Sir Douglas Haig.—Introduced by Gartons in 1920 as the result of crossing Supreme and Naked Oat of China.[1] Grain large and long with thick husk. Straw long and inclined to be coarse. Ear sided and compact with three to five grains per spikelet. The spikelets resemble those of the Naked Chinese Oat. An early ripening variety, only suited to soils in good condition.

[1] **Earl Haig**, a new introduction by Gartons, and derived from the same parents as Sir Douglas Haig, is said to be an improvement on the latter in that it ripens earlier, has shorter straw, and blacker grain with a thinner husk.

E.—BLACK BELL GROUP.

The varieties within this group are relatively unimportant. They include Black Bell 1, Black Bell 2, Black Bell 3, Black Great Mogul, Black Mesdag, Orion and Bountiful. With the exception of Bountiful and Black Mesdag, a Dutch variety, they are of Swedish origin and have not proved to be as suitable for growing in this country as the white oats from the same source. Unlike the Black Tartarian group the ear is open and comparatively long.

Orion is remarkable in that it is the earliest ripening variety at present grown.

Bountiful.—Introduced by Gartons in 1908 and now extensively grown. Grain large, black, and glossy. Straw long and strong, and of good feeding value. Ear large and open, with spikelets bearing two grains. Though grown as a winter oat on good soils its other features call for the inclusion of Bountiful in this group.

2. STRAW PRODUCERS

A.—POTATO GROUP.

This group includes practically all the well-known old varieties, viz.: Potato, Hopetoun, Fellow, Hamilton, Longhoughton, Castleton Potato, Clemrothery, Berlie, Angus, Providence, and White Cluster. Radnorshire Sprig, grown in Wales, is a black oat, belonging to this group, while the white varieties Glebe, Cariss, and Grange, bred by the late Dr. Wilson of St. Andrews, are also of the same type. All are characterized by producing a big bulk of good quality straw, a moderate yield of grain of exceptional milling quality, and by their prostrate habit of growth and consequent vigorous tillering. The ears are large and open, with numerous spikelets bearing either one or two relatively small grains. The straw is generally long and fine and apt to lodge. Such varieties can be successfully grown on the poorer soils.

Potato.—Found growing in a field of potatoes in Cumberland in 1788. Fairly popular in England at present and the most extensively grown oat in Scotland. Time of ripening medium. Grain white, plump and egg-shaped, and apt to be shed at harvest. The popularity of this oat is due to the high total yield per acre under average conditions, although in yield of grain alone it is surpassed by many of the grain producers, i.e. Abundance, Victory, and Yielder types, under good soil and climatic conditions.

Hopetoun.—A selection from Potato introduced by Mr. Patrick Shirreff about 1820. Seldom grown at present.

Fellow.—The Fellow series also selected from Potato includes Early Fellow, Fine Fellow, and Long Fellow. Introduced by Shirreff about 1862 but now of no importance.

Hamilton.—A productive strain of Potato, grown in Scotland, Wales, and Northern Ireland. Selected by Hamilton of Steppes. Hardier than Potato.

Longhoughton.—Very similar to Potato.

Castleton Potato.—A recent selection from Potato made by Mr. J. Runciman, Castleton, Banffshire. Except that the grain is larger and more spindle-shaped this oat closely resembles Potato. It is also more productive.

Clemrothery.—A sub-variety of Potato but with better developed foliage. Recommended for soiling or ensilage purposes.

Radnorshire Sprig.—Of the remaining varieties Radnorshire Sprig is the most important. This variety does exceedingly well in Wales on soils of average fertility, and produces a relatively high proportion of grain to straw. It tillers well and ripens early but is rather liable to lodge. It is a variety of promise.

Varieties in many respects similar to those of the Potato group include the following: Sandy, Tam Finlay, Blainslie, and Ceirch du Bach, the last mentioned being a black oat grown only in Wales.

In general these varieties tend to produce a greater bulk of straw and a lower proportion of grain to straw than the typical members of the Potato group.

Sandy.—Introduced in 1824 and obtained from Mr. Pirie's farm of Milton in Aberdeenshire by his shepherd Sandy Thomson. Thought by some to have been grown in the

Lothians prior to this. Grain pale yellow with a reddish tinge, narrow and comparatively short, and of splendid milling quality. Straw apt to lodge. Spikelets very numerous. Medium to late in ripening. Suitable for growing on poor soils.

Tam Finlay.—Also called Early Poland or Lightfoot. Introduced from Poland and first grown by Tam Finlay, an Ayrshire farmer. Grain long and thin. Recommended for growing on cold stiff soils and under unfavourable climatic conditions. Late in ripening and better suited for forage purposes.

Blainslie.—Also known as Barbachlaw. Grown to some extent in the Carse of Stirling and the south-east of Scotland, and renowned for its tillering power. Resembles Tam Finlay, but later in ripening and with slightly larger grain. Ear exceptionally large and open.

B.—GREY WINTER GROUP.

This group includes Grey Winter, Black Winter, and Dun. Bountiful and Marvellous, because they are winter-sown varieties, are mentioned under this heading although in other respects they are fundamentally different.

Grey Winter, Black Winter, and Dun are of obscure origin and have been in cultivation for a long time. They are characterized by their prostrate habit of growth in the early stages of development, their great tillering propensities and large straw yield, their hardiness, and their well developed open panicles with either one or two grains per spikelet. The grain is long and thin with a very fine husk.

Grey Winter.—Probably of Continental origin. Exceptionally hardy and the most common winter oat in cultivation. Grain greyish in colour, with lighter streaks along the nerves. Straw tall and of good quality, but inclined to lodge on rich soils. Suits poorer soils better than the other varieties within this group. If spring-sown, Grey Winter is very late in ripening.

Black Winter.—Introduced probably from France or Belgium. Grain black; straw long and strong and stands well. Not so hardy as Grey Winter but better suited for soils in good condition.

Dun Oat.—Origin unknown. Similar to Grey Winter but grain reddish brown.

Bountiful. See p. 153.

Marvellous. See p. 152.

MILLING PROPERTIES

There is very great variation in the milling properties of oats, and some of the grain producers in particular, on account of their relatively thicker husk and consequent smaller proportion of kernel, cannot be classed as good milling oats. It is not surprising therefore to find that straw producers with their thinner husk are still preferred in many parts of the country; indeed, there is to some extent a prejudice against grain producers for milling purposes which is not altogether justified by actual facts.

When dealing with good milling oats 6 bushels (240 lb.) should produce 10 stones (140 lb.) of meal, and that is often taken as a standard of production of *meal for corn*. It is equivalent to $1\frac{2}{3}$ stones of meal per bushel of oats.

The majority of the straw producers are up to this standard of meal production, and in some cases the yield of meal per bushel of grain is particularly good.

Some of the grain producers, such as Leader, Hero, Storm King, Record, and Yielder are, as a rule, considerably below this standard of meal production, because they show proportionately more husk than the

straw producers; but even though the yield of meal per bushel may be small from these varieties, that does not matter much. The real test is *meal per acre* and not per bushel, and even the varieties named, though they could not be classed as good milling oats, yield under suitable conditions far more meal per acre than the straw producers.

It is, however, very fortunate that amongst the grain producers there are several varieties that are not only capable of giving a heavy yield of grain, but which also mill well. That has been conclusively proved, with the result that these varieties are finding more favour with millers than they did formerly.

The following table gives the results of milling tests with varieties of oats grown on demonstration areas in the south-west of Scotland, and in connection with the West of Scotland Agricultural College. The milling tests were in every case carried out by the nearest local miller, and every possible precaution was taken to secure an absolutely reliable result. At some of the centres 20 bushels (800 lb.) of each variety was milled, at other centres a much greater quantity was used for the test.

Centre	Variety.	Yield of Meal per Bushel.	Yield of Grain per Acre.	Meal Production per Acre.	
		Pounds.	Bus. (40 lb).	St.	Pounds.
Bridge Mill, Glenluce (1919) ..	Potato	23·3	58	96	7
	Victory	22·5	73	117	4
Bridge Mill, Glenluce (1920) ..	Potato	22·6	48	77	6
	Castleton Potato	22·6	55½	88	5
	Crown	24·0	75½	122	4
	Victory	22·2	70¾	112	2
	Yielder	22·1	70	110	7
	Beseler	22·6	60¾	98	0
	Record	21·5	62	95	3
Castle Kennedy, Stranraer ..	Potato	23·8	56¼	97	9
	Beseler	23·3	71¼	118	9
	Victory	23·2	70½	117	0
	Record	22·9	70¾	116	9
Holywood, Dumfries	Potato	22·0	38	59	10
	Beseler	21·8	45	70	0
	Victory	21·0	53	79	7
	Record	19·4	53	73	6
Quhytewoollen, Lockerbie ..	Victory	23·9	67½	115	3
	Beseler	23·6	68	114	8
	Potato	23·3	53½	89	0

The table (p. 155) gives the yield of meal per bushel of 40 lb., and alongside the calculated yield of meal per acre on the fully manured sections is also shown.

It will be seen that of the varieties tested, with the exception of Crown, Potato oats gave, on the whole, slightly more meal per bushel. At the same time the return in meal per acre was in every case the lowest with that variety, there being a difference of as much as 20 stones of meal per acre in some cases.

There is not much difference in the milling properties of Beseler and Victory, but of the two Beseler is rather the better on the average. These two varieties are only very slightly behind Potato in respect of yield of meal per bushel, and they can be classed as excellent milling oats, being amongst the very best of the grain producers in that respect.

Record, as regards its milling properties, is very typical of many of the varieties in the class to which it belongs. The yield of meal per bushel is only medium, but the deficit in that respect is fully made up by the yield of grain per acre.

The quality of the meal from all of these milling tests left nothing to be desired, as it was particularly good in every case. That from Potato oats was in no way superior to the meal from the other varieties; indeed, on the whole, the meal from Victory oats found most favour, but there was very little difference and in every case the quality was excellent.

MOST SUITABLE CLIMATE FOR OATS

A cool and somewhat moist climate is, on the whole, the most favourable for the development of the oat crop; consequently, we find that the great oat-producing countries lie almost wholly within the North Temperate Zone. The oat plant is a very hardy and robust one, as well as a vigorous grower. It grows and ripens at comparatively low temperatures, and a fairly long and cool growing season is conducive to maximum development. On the other hand, if the growing season is too long, harvest is late, and there is greater difficulty in securing the crop in good condition.

When grown under higher temperatures there is a tendency for the grain to get rather thicker in the husk and to show proportionately less kernel; the straw produced under such conditions is also of much less value for fodder purposes.

The climate of Scotland is highly favourable for oat growing, the summer season, as a rule, being moist and cool. The climate of Ireland and the north and north-west of England is also very suitable. Along the east, the south-east, and the south of England the climate is rather dry on the whole for the oat crop, particularly where the soil is also dry, but where there is sufficient moisture in the soil, that compensates in very

great measure for dryness of climate, hence the magnificent crops often grown on the Fen lands in the east of England.

Along the western side of Britain the rainfall is heavier and the climate more moist than along the eastern side, with the result that the yield of straw is higher on the average and of greater feeding value in the west. In the east, however, the crop threshes rather better, and though the yield of straw is not so satisfactory, the yield of grain per acre is, if anything a little higher, and the quality of the grain rather better.

BEST CLASSES OF SOILS FOR OATS

The oat crop, partly on account of the large number of varieties under cultivation, can be successfully grown on a very wide range of soils. Some varieties gave a fair return on the poor thin dry soils, and other varieties, which would fail entirely under such conditions, give an excellent return on the better class of soils.

The ideal soil for the oat crop is a good deep loam or clay loam, and it is on soils of that class, under favourable climatic conditions, that the best yields both as regards quality and quantity are obtained. Soils with plenty of organic matter and moisture, deep alluvial soils, and the strong fen lands are specially suitable for oats. This crop also succeeds well on good clay soils and on peaty and moory soils, provided they are suitably manured to make good their own deficiency; also on the lighter and drier soils in districts where the rainfall is ample during the growing season. The drier soils require a damp atmosphere, but the moist soils can do with a drier climate.

The oat crop does well on decaying turf, and it is often the first crop taken when land has been drained and brought under the plough. The vigorous root development of the oat crop helps to break up the turf more quickly. Under such conditions the crop is apt to be late in ripening, and that should be speeded up by the application of readily available phosphates.

It is on the thin, dry, chalky soils and on very stiff, cold, intractable clay soils that the return is most uncertain.

The amount of water taken up from the soil by the oat crop exceeds that taken by any other of the more important crops; but though moisture is so essential, the crop is not one which can tolerate stagnant water, and where present a yellowish tinge and unhealthy appearance is soon in evidence.

Where oats for seed purposes are desired, grain produced on good clay loams or good clays is generally preferred, other things being equal, and a better change of seed is obtained from soils of that type than from the lighter class of soils.

PLACE IN ROTATION

The oat crop may occupy different places in the rotation, but in a great many rotations two crops of oats are taken, one after grass or lea and another after roots. The oat crop does particularly well on a grassy turf, in fact it succeeds better than any other cereal crop under such conditions; hence it is generally the first crop taken when grass land is broken up. That is the practice that prevails in Scotland, also to a very great extent in Ireland, in Wales, and in parts of England, particularly in the north, but also to some extent in the south.

With a very short rotation and where clover takes the place of grasses, as in the historic Norfolk rotation, wheat is very often taken in place of oats.

Oats are also taken after root crops, such as turnips, potatoes, mangels, &c., and when in that place in the rotation, grasses and clovers are generally sown along with the oats.

Oats may also follow beans, wheat, bare fallow, or one oat crop may follow another. This last method is very often adopted in Scotland on strong soils which are not very suitable for the growth of root crops, and on such soils grass and clover seeds are sown with the second oat crop.

Again, when old grass land is broken up, two crops of oats are very often taken in succession before a root crop, in order to thoroughly break down the turf and get the soil into a finer condition for the growth of that crop. The same method is also resorted to frequently to clean land that is foul, and it is both a simple and effective method of dealing with such land. When two oat crops are taken in succession with this object in view, they should be liberally manured in order to give a thick heavy crop and smother out any weeds that may be present.

This method of cleaning foul land is infinitely better from every point of view than the alternative method often practised, which entails the gathering and burning or carting off of large quantities of couch or other weeds.

Oats may also be grown on the same land year after year for a period of years, provided the scheme of manuring is ample, but a system of continuous corn-growing of this kind should not be adopted unless under very special conditions. It has very decided disadvantages, and under it the benefits resulting from rotation cropping are not obtained.

When sowing oats on lea, provided the ground is clean and otherwise suitable for clover growth, 4 lb. or thereby of red clover seed may be sown per acre. This provides a good deal of valuable grazing in the autumn, after the oats have been removed and when the residue is ploughed in, the land is greatly enriched in nitrogen, and succeeding crops benefit. Experiments extending over three years, and carried out by

the West of Scotland Agricultural College at Kilmarnock, showed that when barley followed oats with which red clover was sown, and the produce ploughed in without being grazed, the barley crop benefited to the extent of 8 bushels per acre.

To give the clover a chance to develop, the seed should be sown on a fine, firm surface and lightly harrowed in, so as not bury it too deeply, and the land should then be firmly rolled.

On soils and under conditions where clovers do not grow successfully, Italian ryegrass may be sown instead with lea oats. That adds materially to the autumn grazing, but does not enrich the land or increase the yield of succeeding crops.

PREPARATORY CULTIVATION

The oat crop, unlike root crops such as potatoes and turnips, requires very little in the way of preparatory cultivation; indeed, there is no crop that demands less in that respect.

When the seed is to be broadcasted, ploughing is the one and only preparatory tillage operation, but with that method of sowing the ploughing must be performed in such a way as to leave a firm, well-set-up furrow so that there may be a good seed bed. The width of the furrow slice should not be too great, particularly in the case of lea. Eight inches represents a very suitable width where a good close seed bed is wanted, but the depth of the furrow may vary from 6 to 10 in. according to the soil. It is often advisable to use a skim coulter if there is much rough grass, as that puts it more completely under.

The furrow slices must be firmly packed, and, in addition, they should have plenty of crest, so as to provide " meat " for the harrows and give a good covering to the seed. Occasionally a drill presser is used to give a firmer and better seed bed, but if the ploughing has been well done there is really little need for the drill presser unless under special circumstances.

After the seed has been broadcasted, the ground is harrowed until the furrow slices are broken down and the surface levelled. Very often as many as six or seven turns with the harrows are required in the case of lea, but when oats are grown after root crops two or three turns generally prove ample. The first two turns should be in the direction of ploughing in the case of lea, otherwise some of the furrow slices might be opened a little and some of the seed too deeply buried. After the first two turns the harrowing should be at an angle to the direction of ploughing, as that breaks down the furrow slices more effectively, but the final turn is generally in the direction of ploughing. Special attention should always be devoted to the furrows between the ridges. They should be made as shallow as possible, otherwise they prove a source of trouble

when cutting. An extra turn with the harrows always helps to fill them up.

If the seed is to be drilled in there is no need to plough in such a way as to leave a good seed bed. A much wider furrow may be taken, and if deemed advisable it may be practically inverted, as the ground has to be cultivated or harrowed prior to drilling in the seed. For this purpose the ordinary spring tine harrow may be used, or on suitable soils the disc harrow, or even an ordinary heavy-toothed harrow. When the surface has been reduced to a sufficiently fine state the seed is drilled in. The majority of drills now in use are disc drills. The disc, like the coulter, cuts out a groove in which the seed is deposited. The distance between the discs or coulters, and consequently between the rows, is generally 6 or 7 in. If the ground has been well cultivated before the seed is drilled in, a single turn with the harrows will suffice to level the surface.

When the harrowing has been completed, the final operation, whether the oats have been broadcasted or drilled in, is rolling. The rolling is practised primarily with the object of breaking down any clods and firming and levelling the surface, but it also has a marked effect on temperature and on the moisture supply, and when rolling is done just after sowing operations have been completed, as should be the case with spring-sown oats, it is frequently the means of bringing away the crop more quickly. With winter-sown oats the ground should not be rolled but left rough until the spring. When grasses and clover seeds are to be sown down with oats, either for temporary or permanent pasture, the seed should be sown on the rolled surface, which should then be lightly harrowed, and the ground again rolled. This entails extra work, but with a big proportion of very small seeds in the mixture it is well worth the extra labour involved.

TIME AND MANNER OF SOWING

The actual time of sowing must always be regulated by the condition of the soil, as it is of the utmost importance that it be in suitable condition for the reception of the seed when sowing takes place. With this reservation, winter oats are generally sown in September, October, or early in November, the time of sowing being very similar to, but preferably earlier than that for winter wheat. Spring or ordinary oats, on the other hand, are far more widely grown than winter varieties, and are sown at any time from the beginning of February on to the end of April, and even in special cases to the middle of May. In the south a commencement is generally made with the sowing early in February, if the ground is in suitable condition, and in Scotland the seeding is generally proceeded with as soon after the middle of March as the weather and soil conditions will permit. Experiments conducted by the West of Scotland Agricultural College on the best time to sow ordinary varieties

of oats point to February as being, on the whole, the time of sowing that gives the largest yield and the most profitable crop. There is, however, as a rule a very great amount of ploughing to overtake during, and subsequent to, the month of February, so that, apart altogether from weather conditions, it is not always practicable to sow then, though that time of sowing has much to recommend it.

Early-sown oats always suffer less damage from attacks of wireworm, frit-fly, and similar pests, as they are better established at the time these pests are most in evidence. Runch and charlock are also much less prevalent in early-sown oats, even on land subject to a strong growth of these weeds, because the young plants are readily injured by frost. For the same reason these weeds are never very prominent in crops of winter-sown oats, though they often materially reduce the yield and quality of spring-sown crops. Early-sown oats also suffer less from drought in early summer on account of greater root development, and, moreover, they are not so liable to lodge, which is a feature of very great importance.

Although oats are sometimes sown as late as May it is not a good practice, and should never be made a general one. The yield of straw may, and generally does, prove quite satisfactory, but the yield of grain suffers very materially.

Two methods of seeding are practised in the case of the oat crop, namely, broadcasting and drilling. Broadcasting, as the term implies, denotes the distribution of the seed over the surface. The broadcasting may be done by hand, by hand machine, and by the ordinary broadcast sowing-machine. When the sowing is done by hand, as is generally the case on the smaller farms, a special sowing sheet is used. This is suspended from the shoulders, and carried in front in such a way as to leave both hands free for the sowing. There is an art in sowing uniformly, and a considerable amount of skill is required, although the operation seems fairly simple. The width taken at a time may vary from 12 to 15 ft., and, with sufficient assistance for refilling, an expert sower can quite easily cover 20 acres in a day. If only one hand is used, the width taken at a time is generally 8 to 9 ft., and, with sufficient assistance for refilling the sowing sheet, from 12 to 14 acres represent a fair day's work.

In some cases a small hand sowing-machine, known as a "fiddle", is used for broadcasting. The fiddle is slung from the shoulders, and carried on the left side. The seed is distributed by means of a small rotary disc, which is turned first one way and then the other by pushing the bow through and drawing it back. The width taken at a time is generally about 15 ft., and the area that can be covered in one day, with the necessary assistance for refilling, is very similar to that covered by an expert sower using both hands, but with the fiddle there is always greater loss of time in refilling.

The ordinary single-horse broadcast sowing-machine is also widely used. It gives very even distribution of the seed, and is a speedy method of sowing, from 16 to 20 acres representing a fair day's work.

Broadcasting is practised chiefly on the smaller farms, where the acreage under oats does not altogether justify the purchase of a corn drill; also on rough and stony soils, on steep and uneven land, and on land lifted from old grass and which would not be easily brought into a sufficiently fine condition to admit of drilling.

By the drilling method of seeding the seed is deposited in rows in the soil at a uniform depth. For spring-sown oats the best depth is about 1 in.; the rows may be from 6 to 9 in. apart, or even more if it is desired to carry out intertillage with the object of cleaning the land. It is, however, much better to clean the land by growing a close, thick, heavy crop than by intertillage. As pointed out in connection with preparatory cultivation, the land requires to be cultivated or harrowed before the seed is drilled in. In the case of broadcasting, the harrowing takes place after the seed has been sown. The drilling method of seeding is not nearly so speedy as broadcasting. Two horses are required for the ordinary corn drill, and 8 to 10 acres represent a fair day's work.

Close drilling, as a rule, gives a better return per acre than wider drilling, but when grass and clover seeds are being sown with the oats too close drilling is not desirable, as the young plants do not then get quite the same chance to develop.

In experiments conducted by the West of Scotland Agricultural College at Holmes Farm, Kilmarnock, it was conclusively demonstrated that, with the same amount of seed per acre, close drilling gave the largest and by far the most profitable crop. The method of seeding and the average results obtained per acre were as follows:

Method of Seeding.	Yields per Acre.	
	Dressed Grain.	Straw and Chaff.
	Bus.	Cwt.
6 bushels per acre, drilled in rows 6 in. apart	$89\frac{1}{2}$	$39\frac{1}{4}$
6 ,, ,, ,, ,, 7 ,, ,,	81	34
6 ,, ,, ,, ,, 8 ,, ,,	77	33
6 ,, ,, ,, ,, 9 ,, ,,	$75\frac{3}{4}$	$32\frac{3}{4}$
7 ,, ,, broadcasted	$86\frac{1}{2}$	$37\frac{3}{4}$

It will be seen from the above results that, though the same amount of seed was applied per acre, there was a steady falling off in yield as the width between the rows was increased. The amount of seed drilled in per acre may be considered by some to be more than necessary. The

variety used in the experiment was Beseler's Prolific, a typical grain-producing variety, the individual grains of which are fairly large, and, with such a variety, 6 bushels per acre is not an excessive amount of seed under average Scottish conditions.

It will be observed that in the same experiment the second best result was obtained from broadcasting at the rate of 7 bushels per acre, and that with the exception of the first method of seeding, viz. drilling in rows 6 in. apart, the extra bushel of seed required for broadcasting was more than repaid in the increased crop which resulted. This result has been confirmed by experiments carried out by the North of Scotland College of Agriculture, and recently reported on in the *Scottish Journal of Agriculture*.

In actual practice, the broadcasting method is very much speedier than drilling; moreover, apart from the extra seed required per acre, it is a much cheaper method, and it has the further advantage that it can be adopted on all classes of soils provided there is a suitable seed bed. In certain cases, e.g. heavy soils, in " catchy " weather it is the only practicable method.

Drilling, on the other hand, while a slower method of seeding than broadcasting, is fully the best method on fairly level land where the soil is good and the stones are not so numerous as to interfere with the drilling. It is also much the better method where it is not possible to plough in such a way as to leave a good seed bed, as, for example, after fallow or root crops. By the drilling method the seed can be deposited at a uniform depth, and that in turn gives a more even growth and greater uniformity in ripening.

SEED REQUIRED PER ACRE

There is great variation in the amount of seed required per acre; it may vary from as little as 3 bushels up to as much as 8 bushels, but the quantity required is determined in great measure by such factors as the following:

Manner of Sowing.—It has already been pointed out that there is a considerable saving in the amount of seed required per acre when the seed is drilled in, as against being broadcasted. The actual saving in seed varies from 1 bushel per acre, in the case of typical straw-producing varieties, to fully $1\frac{1}{2}$ bushels with some varieties of the grain-producing type. For example, if 5 bushels of Sandy oats and $7\frac{1}{2}$ bushels of Yielder were required per acre to give a full seeding when broadcasted, 4 and 6 bushels respectively would suffice when drilled in.

The Tillering Capacity.—Oats that tiller freely do not require to be seeded so thickly per acre as varieties that tiller very little. That is one of the reasons why practically all the grain-producing varieties

require to be seeded more thickly. They are not capable of tillering to the same extent as the straw-producing varieties.

The Size of the Individual Grains.—There is great variation in this respect according to the variety, but variation is also possible in any one variety. With smaller seeds fewer bushels per acre will suffice, because each bushel will provide a larger number of seeds. In the case of some varieties a bushel may contain somewhere about 600,000 seeds, but with others again the number of seeds per bushel may be little more than 400,000; consequently, when the individual grains are larger a greater number of bushels per acre will be required. For the most part the grains are larger in the typical grain-producing varieties, and that is another reason for the seeding being more liberal in the case of these varieties.

Soil and Climate.—This does not always receive the consideration it merits, as it should be an important factor in determining the rate of seeding. When conditions are adverse, as regards both soil and climatic conditions, the rate of seeding should be rather greater for the reason that a percentage of seeds, which might have given rise to robust plants under more favourable conditions, may fail to do so under conditions that are less favourable. Again, in the case of soils that are full of couch grass, pearl grass, or similar weeds, the rate of seeding should be a little thicker to deprive these objectionable weeds of space, light, and air, and so keep them better under.

Germination.—No factor is of greater importance than this one, as it is on the germination that everything else turns. Too often the germinating capacity is just taken for granted; but the farmer who does so is working entirely in the dark. After a bad harvest, an autumn frost, or even in the case of a good harvest, if " leading " has been proceeded with rather too soon and heating takes place in the stack even to a small extent, germination is materially affected. If such grain is used for seed purposes, the resulting braird may be very thin, even though the normal number of bushels has been allowed per acre. The seed should always be tested for germination prior to sowing.

Time of Sowing.—With the oat crop the time of sowing does not affect the quantity of seed required, as it does with the wheat crop, for the reason that oats do not tiller nearly so much as wheat. When oats are sown early in the year the rate of sowing instead of being below the normal should really be above it, because a greater number of the plants fail to develop.

A series of experiments was conducted by the West of Scotland Agricultural College to ascertain the best rate of seeding under average conditions, and it was conclusively demonstrated that in the case of a variety of oat such as Potato, when the seed was broadcasted the rate of seeding should be about 3,000,000 germinating seeds per acre or

approximately 5 bushels. Smaller yields were obtained from 2,000,000 seeds (approximately $3\frac{1}{3}$ bushels) and from 4,000,000 seeds (approximately $6\frac{2}{3}$ bushels) than from the first-mentioned rate of seeding. With typical grain-producing varieties, such as Yielder, Victory, Record, &c., fully 7 bushels are required as a rule to supply the same number of seeds, but, even at the rate of 7 bushels per acre, these varieties are at a disadvantage, as they are not capable of tillering to the same extent; consequently they should not be sown on the basis of equivalent numbers of seeds per acre, but relatively greater, otherwise the crop will ultimately be thinner on the ground and the yield of straw per acre rather less.

This point is not always fully appreciated, and the fact of its being overlooked is often the cause of disappointment regarding the yield and quality of the straw from certain of the grain-producing varieties.

When the seed is drilled in instead of being broadcasted, 1 bushel less will suffice under equivalent conditions in the case of straw-producing varieties, and $1\frac{1}{2}$ bushels less in the case of the majority of the grain-producing varieties.

CHANGE OF SEED AND BENEFITS THEREFROM

Unless soil and climatic conditions are specially favourable, oats grown on the same farm or in the same locality year after year without the seed being changed generally degenerate to some extent and give a diminished yield. Fortunately this state of matters can be entirely obviated by a judicious change of seed from time to time as may be required. By the introduction of fresh seed we very often get greatly increased vigour of growth, which results in a healthier, a better, and altogether a surer crop. If the change of seed is effected under certain conditions it will also result in an earlier harvest.

To obtain the maximum benefit from a change of seed very careful selection is necessary, and a knowledge of the previous history of the seed, including the locality in which grown, is required before one can judge as to its suitability for the purpose in view. Appearance of the sample is certainly very important, but, after all, information as to the soil and climatic conditions under which the seed was produced is of equal, if not of greater, importance, yet in purchasing seed that aspect of the matter is often entirely overlooked and undue stress put on appearance.

If seed is taken from a district noted for earliness and productiveness to a district where the oat crop is later in ripening and the yield not so good, very great benefit results, as there is a tendency for the crop to retain, in part at least, its early-ripening, high-yielding power; the crop that results is above the average for the locality, though rather behind that for the district from which the seed came. On the other hand,

a change of seed may have a detrimental effect if due care is not taken in effecting the change. For example, if seed were taken from a poor late district to a better grain-growing district, the crop would be later and poorer than the average for the locality; hence such changes of seed should always be avoided.

As a general rule, in changing seed an endeavour should be made to get it from a better grain-growing district, where the soil is a good loam or even a clay loam. Where the change is made partly for the purpose of getting an earlier harvest, the seed should always be obtained from an earlier district. Even in good grain-growing districts, a change from time to time is often the means of securing renewed vigour and of increasing the yield; under such conditions a change of seed every four or five years is all that is necessary, and no benefit is likely to result from more frequent change. When conditions for oat growing are much less favourable, a change of seed should really be effected every alternate year, and in special cases every year, particularly if typical grain-producing varieties are grown, as these often tend to degenerate more rapidly. Under such conditions the yield often falls as much as 5 or 6 bushels in a single season compared with the yield where fresh seed is introduced.

Certain of the black varieties of oats, if grown on hard, dry land instead of on peat, require a change of seed every second year, otherwise the yield falls considerably, and the grain gets much lighter in colour. This is particularly noticeable with Black Tartarian, and in consequence seed raised on mossy soils is preferred.

There is a very good market for Scottish seed oats both in England and in Ireland, and the change has been found to be a good one. Such areas in Scotland as the Lothians, Berwickshire, and parts of Stirling, Perth, Fife, Forfar, and Ross-shire are all noted seed-producing areas.

SELECTION AND TREATMENT OF SEED

In the selection of seed oats, germination should always receive special attention, for, as already pointed out, that is one of the main factors in determining the rate of sowing.

Fully matured seeds always germinate better than unripe seeds, and with the former there is a larger store of nutriment available to keep the young plants going till they are fully established. Consequently, in selecting seed, plump well-filled, ripe grain of good colour is desired. When the weather has been adverse at the time of harvesting, and the crop has had to stand in the stook a considerable period, the grain shows the effect of the weather, being darker in colour, and the germinating capacity is generally materially modified.

The same is true if "leading" has taken place too soon, and if

"heating" has resulted even to a slight extent. Under such circumstances, the grain is brownish in colour and the germination is low; consequently it should not be used for seed.

In addition to high germinating capacity, the grain selected for seed purposes should be "pure" or "true to its kind". It is often difficult to get a perfectly pure sample, owing to the fact that, no matter how carefully the threshing may have been carried out, odd grains previously left in the mill get in amongst the produce of the next lot threshed. Purity is of great importance at any time, but it is of special importance when the grain is grown mainly for seed purposes, and too great care cannot be exercised during the process of harvesting and threshing.

Further, the oats for seed purposes should be uniform as regards the size and appearance of the individual grains. If there are large grains and small grains present, the large grains generally give rise to plants which make a more rapid growth at first, with the result that, with a somewhat mixed sample of seed as regards size of individual grains, the same even growth and development is never obtained. The difference was particularly noticeable in some experiments on the selection of seed conducted by the West of Scotland Agricultural College during season 1919. A mixed sample of seed did not give such uniform growth as when the large grains and small grains were sown separately. The largest grains gave rise to fully the earliest crop, and the small grains to the crop which was latest in ripening. The sowing of small grains—"bosom pickles"—has often been recommended as likely to give a good result; but in the case under consideration the large grains gave not only the earliest crop but the largest yield of grain and straw as well, the second best yield being obtained from the mixed sample of seed, and the poorest yield from the small grains. The experiment was conducted on plots $\frac{1}{10}$ of an acre in extent; Victory was the variety of oat grown, and the seeding was at the rate of 3,000,000 seeds per acre. The actual yields per acre were as follows:

Kind of Seed.	Weight of Grain.	Weight of Straw.
Large grains ..	77½ bus.	40 cwt.
Small grains ..	58 ,,	37 ,,
Mixed sample ..	66 ,,	39 ,,

The grain selected for seed purposes should also be free from the smut fungus, as when present it very materially reduces the yield and value of the crop. In this connection it is now well known that the typical grain-producing varieties of oats, such as Record, Yielder, Leader, &c., suffer very much less from smut than the older varieties, such as

Sandy, Potato, and similar varieties of the straw-producing type. Varieties like Victory and Beseler, which are the best milling oats amongst the newer varieties, are not quite so immune to smut as the varieties already mentioned, but they do not suffer to anything like the same extent as the ordinary straw-producing varieties already referred to.

In experiments conducted in Argyleshire, where smut is particularly prevalent amongst oats, it was found that treatment with formalin solution was an effective means of prevention; not only so, but the yield per acre was very greatly increased, the actual increase per acre being 20 per cent in grain and fully 15 per cent in straw. It is therefore clear that the eradication of smut would greatly increase the average yield of oats per acre, and, as the cost of treatment is trifling, one is surprised that it is not more generally adopted where varieties susceptible to smut are grown. For particulars as to treatment see article PARASITIC FUNGI OF CEREALS.

ELECTROLYTIC TREATMENT OF SEEDS

Electrolytic treatment of the seed has been advocated as a means of increasing the yield of the oat crop. The process consists in soaking the grain to be used for seed purposes in a tank containing certain salts and subjecting it, while in the tank, to the action of an electric current. Thereafter the grain is dried at a temperature of 110° F. and is then ready for sowing. The cost of treating the seed where there is suitable equipment amounts on the average to about 3*s.* 6*d.* per bushel—14*s.* per acre if the rate of seeding is 4 bushels, or 21*s.* per acre if the rate of seeding is 6 bushels.

The advocates of the electrolytic treatment of seed prior to sowing claim that, at relatively small cost, the yield per acre can be very materially increased, but this claim is not fully confirmed by actual experiments. On the whole the results are variable. In some cases treatment appears to materially increase the yield; in other cases it appears to be without effect; while still in others it appears actually to have a detrimental effect.

In view of the somewhat conflicting results obtained, it is clear that this method of treatment is not one that can be relied on to increase the yield in all cases, and further investigation is required to ascertain the conditions under which it has the most beneficial effect.

It should always be borne in mind that this method of treatment is not really a substitute for manuring. It may produce more vigorous plants and enable the crop to make better use of plant food material that may be available, but if so it is bound in so doing to deplete the soil to a greater extent of certain of its manurial ingredients, and if persisted in without adequate manuring the ultimate effect will be exhausting.

In the light of our present knowledge electrolytic treatment of seeds, though it at times has a very beneficial effect, cannot be recommended as a reliable method of increasing the yield of the oat crop. A slightly increased outlay per acre in manures is likely to be attended with better and more certain results.

MANURING OF OATS

Few of the common farm crops respond better to manuring than the one now under consideration; but as bad effects, such as lodging, may result from an injudicious use of certain manures, the subject calls for, and merits, very full and careful consideration.

The actual manurial requirements vary to some extent according to the nature of the soil, the condition of the soil, the variety of oat grown, and similar factors; but as numerous experiments have been carried out, the needs of the oat crop in the way of manurial ingredients are now pretty well known.

In general, though *lime* is less necessary for oats than for many other crops, the aim should be to keep up a good balance of that ingredient in the soil, because of the far-reaching effects resulting therefrom, and to provide a sufficiency of *nitrogen*, *phosphate*, and *potash* in readily available forms.

The actual part played by each manurial ingredient may be said to have been definitely established, and a knowledge of this is always of great value as a guide to the proper manuring.

Phosphate.—The phosphates, if readily available, have a marked effect in enabling the young plant to develop roots more quickly and get over what is termed the "sitting" or transition stage. When rooting conditions are far from good, as in the case of certain clay soils, there is all the greater need for a liberal supply of readily available phosphates to promote root development.

Phosphates also promote tillering and tend to give a thicker crop; consequently, with plenty available phosphates in the soil, less seed per acre is required, particularly if a variety of oat capable of tillering freely is sown. Throughout the whole period of growth the phosphates are found most abundantly in the growing parts of the plant, and later on play an important part in connection with seed formation. A plentiful supply of phosphate materially increases the fruitfulness of the crop, as measured by the number of grains.

Being intimately connected with seed formation, the ultimate effect of providing a sufficiency of available phosphate is to hasten the ripening of the crop, and this effect is always most marked in late seasons and in late districts.

Potash.—The potash, while not so important in the very early

stages of growth, has a marked effect in strengthening the straw and in rendering the crop less liable to lodge. This effect is very important, as a standing crop means a very great saving of labour in harvesting, apart altogether from the quality of the produce obtained in the case of a standing crop as against one badly laid.

Potash, moreover, being intimately connected with the process known as carbon assimilation (which is really the starting-point for the formation of starch and sugar in the plant), always tends to give well-developed, well-filled grain. The effect in this respect is quite distinct from that produced by phosphates, which tend to increase the number of individual grains, whereas the potash plays an important part in giving plump, well-filled grain.

Nitrogen.—In certain respects nitrogen may be considered the most important manurial ingredient of the three, as it has a very marked effect on the growth and yield. At first the effect is most noticeable in connection with the promise of straw, which results where a sufficiency of readily available nitrogen is applied, but the effect is not confined to the straw, and later it extends to the grain.

If the quantity of available nitrogen is not sufficient for the plant's requirements, the growth is always poor and stunted, and this is true even though plenty of phosphates and potash may be available. On the other hand, excess of nitrogen tends to rush up the crop too quickly, and there is far greater tendency for lodging to result. On that account it is important that nitrogen be not applied in excessive amounts.

Once the young oat plant has taken root, the nitrogen tends to push the growth rapidly on. It thus proves exceedingly useful in the case of an attack of grub or wire-worm, as it often enables the crop to grow away from such pests; consequently less damage results.

It should be pointed out that nitrogen, particularly when applied alone or in excess of actual requirements, has a tendency to prolong the growing period and delay the ripening process, but this effect is counteracted by the earlier ripening tendency produced by phosphates.

When we apply manures to the oat crop we do so primarily for the purpose of increasing the yield of grain and straw, but there are other beneficial effects from the application of well-balanced artificials which are equally as important and which should never be overlooked. These effects briefly stated are as follows:

1. The judiciously manured crop ripens earlier than an unmanured crop. The difference in time of ripening may, and often does, amount to as much as ten days. That is of great importance at any time, but in wet seasons and in late districts it is of special importance.

2. The grain from judiciously manured crops is better filled and

plumper in appearance. The weight per bushel is higher, and consequently the yield of meal per bushel is greater.

3. Well-manured crops are healthier, and they suffer less when attacked by wire-worm, grub, and similar pests. The manures promote tillering and enable the crop to grow away from the pests.

4. On land that is inclined to be foul, a heavy crop of oats smothers the weeds to some extent and keeps the ground very much cleaner. In consequence thereof it is very much easier to prepare for succeeding crops. A poor crop of oats, such as might result on inferior soils where no manure was applied, gives the weeds, and particularly weed grasses, a better chance to develop, and really lays up a store of trouble for the future.

5. The application of well-balanced manures is a safeguard against lodging; the straw is actually strengthened and better able to carry the greater weight of grain which results. This view of the matter is, of course, contrary to that held by most farmers, but the writer has seen it demonstrated repeatedly. It is when there is too much nitrogen applied in the manure, or present in the soil, that lodging is encouraged.

When land that has been under grass for several years is broken up there is generally no need for nitrogenous manures, particularly if white clover has been at all abundant in the pasture, or if concentrated feeding stuffs have been fed to the grazing stock. In such cases the land is rich in nitrogen; indeed, it is often too rich in that respect. On the other hand, applications of phosphates and potash tend to counteract the effects from excess of nitrogen, the former by speeding up the ripening process, and the latter by producing straw which does not lodge nearly so readily.

As regards the phosphatic manuring, superphosphate has been found to be fully the best form of phosphates under normal conditions, chiefly on account of the fact that it is readily soluble and quick in its action. It should be harrowed in at the time of seeding, as it has always most effect when applied at that time.

Basic slag may be used to replace superphosphate on peaty or mossy soils or on heavy clays, but being slower acting the quantity required is greater by about one-half. It is an advantage in the case of basic slag if it can be applied some time before seeding.

Bone manures are rather too slow for the oat crop, excepting dissolved bones, which are very much akin to superphosphate, and steamed bone flour, which in rate of action is very similar to the better grades of basic slag.

There is comparatively little difference as far as the chief potash manures are concerned as they are all readily soluble, and any one can be used to replace another. Kainit and potash salts supply more common

salt than the others, and, as the salt often has a beneficial effect on the oat crop, these two sources of potash were fully the most widely used in manuring this crop in pre-war days. When sowing down with grasses and clovers, it is, however, always safer to use a purer form of potash, such as potassium chloride (muriate of potash). The Alsatian potash now coming into this country is proving a very suitable source of potash for the oat crop.

As regards the chief nitrogenous manures there is, as in the case of potash, very little difference in effect, provided the dressings are varied so as to supply equivalent amounts of nitrogen.

Nitrate of soda and nitrate of lime should be applied as top dressings just as soon as the crop has brairded. Sulphate of ammonia should be applied at the time of seeding and harrowed in. Nitrolim should be dealt with in the same way, or it may even be applied with advantage a few days prior to seeding.

Nitrate of ammonia and muriate of ammonia have not yet been very fully tested, but there is little doubt that they will also prove excellent nitrogenous manures for the oat crop.

The manurial dressing should be varied according to the conditions which prevail, but the quantity to be applied generally falls within the following limits:

1½ to 4 cwt. superphosphate (assuming the 30 per cent grade).
1 to 3 cwt. kainit (or the equivalent of any other potash manure).
0 to 1½ cwt. sulphate of ammonia (or equivalent as nitrolim, nitrate of soda, &c.).

A well-balanced dressing suitable under average conditions would be supplied in the following:

2½ cwt. superphosphate (30 per cent, or equivalent of a lower grade).
2 cwt. kainit.
¾ cwt. sulphate of ammonia.

Such a dressing generally increases the yield by about 10 to 12 bushels of grain and 10 cwt. of straw, and it therefore proves very profitable from every point of view. There is not the slightest doubt that the average yield of oats per acre could be very greatly increased, and profitably increased, by judicious manuring, and it is a matter for regret that the practice is not more general.

The following table gives the average yields per acre obtained in seventeen different experiments, conducted in seasons 1912, 1913, and 1914, by the West of Scotland Agricultural College. The centres were widely scattered, and soil and climatic conditions varied considerably:

Plot.	Manure Applied per Acre.	Yield per Acre.		Increase over Unmanured Plots.	
		Grain.	Straw.	Grain.	Straw.
		Bus.	Cwt.	Bus.	Cwt.
1	No manure	41¼	28¼	—	—
2	2 cwt. superphosphate (30 per cent)	43½	29½	2¼	1¼
3	2 cwt. superphosphate, 2 cwt. kainit	46¼	31¾	5	3½
4	2 cwt. superphosphate, 2 cwt. kainit, 1 cwt. nitrate of soda	53½	38	12¼	9¾
5	2 cwt. superphosphate, 2 cwt. kainit, 134 lb. nitrate of lime	54½	38¼	13¼	10
6	2 cwt. superphosphate, 2 cwt. kainit, 87 lb. sulphate of ammonia	54½	38½	13¼	10¼
7	2 cwt. superphosphate, 2 cwt. kainit, 97 lb. nitrolim ..	51¾	36½	10½	8¼

In the above experiment the same amount of nitrogen was applied to each of the four plots getting a nitrogenous manure, and all the manures were harrowed in at the time of seeding, excepting nitrate of lime and nitrate of soda, which were applied as top dressings just after the crop had brairded.

The yields recorded above show to what extent manuring may raise production, and they emphasize the importance of supplying a complete manure containing phosphates, potash, and nitrogen.

The oat crop, compared with many other crops, is not an exhausting crop. At the same time it does remove from the soil considerable amounts of nitrogen, phosphate, and potash, particularly when heavy crops are produced. With medium crops the quantity removed is proportionately less. The amounts of the manurial ingredients removed in a crop of 48 bushels of grain and 30 cwt. of straw are approximately as follows:

	Nitrogen.	Phosphoric Acid.	Potash.
Grain (48 bushels) ..	33 lb.	14 lb.	10 lb.
Straw (30 cwt.) ..	21 ,,	8 ,,	40 ,,
Total	54 lb.	22 lb.	50 lb.

54 lb. of nitrogen represents approximately the amount contained in $2\frac{1}{2}$ cwt. sulphate of ammonia, 22 lb. phosphoric acid the amount contained in $1\frac{1}{2}$ cwt. superphosphate (30 per cent grade), and 50 lb. potash the amount contained in about $3\frac{1}{2}$ cwt. kainit.

In manuring we do not really aim at providing in the manure all that the crop requires, but rather at supplementing with quick-acting forms of nitrogen, phosphates, and potash the amounts of these ingredients in the soil.

It is clear from these figures that even though the oat crop is fairly liberally manured it must make a considerable demand on the soil for nitrogen and potash. The larger the crop the greater will be the demand; and, consequently, when large crops are aimed at, the manuring should be all the more liberal.

CULTIVATION AND TREATMENT DURING GROWTH

Little is required in the way of cultivation or treatment after the rolling in spring. In a few cases, when the oats have been drill-sown with the rows at a considerable distance from each other, such cultivation as hoeing may be attempted, but as a rule it is not necessary, and it is only in rare cases that it is practised.

Though cultivation is not common, weeding of the crop should never be neglected, particularly if thistles are prevalent, as these take up much valuable space; further, they are troublesome when handling the crop, and they reduce the yield. With the introduction of the "self-binder", thistles have in many cases received rather less attention than they did prior to that time.

They are best dealt with before they get too strong and can be easily pulled up by hand, the hand being protected by a glove with a leather palm. The thistles are much easier pulled after rain than in dry weather. The roots come away much cleaner in the former case; in the latter they are more apt to break.

Sometimes the pulling is done by what are called "weeder-clips" instead of by hand, but this method is not now much practised, and though of interest, is not so good; further, some of the grain is likely to be caught and pulled up at the same time. Burns gave us an example of bad farming—though possibly good poetry—in the following:

> The rough burr-thistle spreading wide
> Amang the bearded bere,
> I turned the weeder-clips aside
> And spared the symbol dear.

Sometimes the thistles, instead of being hand pulled, are cut—"spudded"—just below the surface of the ground with a sharp chisel-

shaped tool, and this method is very much speedier than pulling, but not quite so effective unless the root is cut well below the surface of the ground. No matter what method is adopted, thistles should be dealt with before the oats get to a height of more than 8 or 9 in., otherwise they are not so easily seen and more damage is caused by trampling.

Runch (*Raphanus raphanistrum*) and charlock (*Sinapis arvensis*) are also very prevalent amongst oats in many localities, but these weeds are best dealt with by spraying with copper sulphate solution when they are from 4 to 6 in. in height.

The runch is much more difficult to kill than the charlock, and where it is prevalent the spraying should be carried out early, otherwise a big percentage of the plants will survive. For charlock spraying, a 3 per cent solution at the rate of 50 gall. per acre (15 lb. copper sulphate) generally proves quite effective, but for runch it is better to use a 5 per cent solution (25 lb. per acre). The solution may be applied either by horse or hand sprayer, but where a large acreage has to be dealt with the hand sprayer is much too slow. To be effective the solution must be applied in the form of a fine, misty spray. A dry day should be selected for the operation, and the spraying carried out before it is too late in the day, otherwise it is not as a rule so effective. The oat plant, with its smooth leaf, does not suffer from the spraying except for a partial browning of the leaf; it soon recovers from that, and, with the weeds effectively put down, makes more vigorous growth thereafter.

Runch and charlock can also be eradicated by hand pulling, but only at very great cost for labour and with considerable damage to the crop from trampling; consequently spraying is the best method to adopt, being infinitely cheaper, and, if properly carried out, very effective.

By the eradication of runch and charlock the yield and value of the produce is greatly improved, but where treatment is neglected, and these weeds are allowed to mature and seed, not only is the value of the produce materially lowered, but a store of trouble is laid up for the future.

HARVESTING

Spring-sown oats require as a rule about eighteen or twenty weeks from the time of sowing till they are ready for harvesting—more or less according to the season. It takes about three months to reach the "shooting" stage, and a further period of about six weeks from the time of shooting till ready for cutting. Oats sown in autumn or early winter, though ready for cutting earlier, really hold the ground much longer, as they make little progress during the winter months, but with these also the actual ripening period is just about six weeks.

It is specially important for several reasons that oats be cut before they are ripe, and in practice we very often err in this respect by waiting

too long before commencing the cutting. If the crop is allowed to get quite ripe before being cut, you certainly get nice, plump, well-filled grain, but a good deal of the very best of it is apt to be lost in the process of harvesting, particularly if much handling is required. There are great differences amongst varieties of oats in this respect. Some, such as Potato and Abundance, part with their grain very readily if quite ripe, but other varieties, such as Sandy, Victory, and Leader, retain it better than many others, though all varieties shed some of the grain no matter how carefully the handling may be performed. Apart altogether from the loss of grain that may result with over-ripe oats, the straw is not so good, as it is sapless, brittle, less palatable, and of inferior value for fodder.

By cutting a little early the total yield is actually higher, as the oats continue to ripen in the stook, but they do not part so readily with grain during the handling, as the chaff adheres more firmly to it.

Too early cutting on the other hand must be avoided also, as it is open to equally serious objections. For example, the grain does not fill properly, and consequently it never has the same nice, plump appearance. For that reason there is more light grain and the yield per acre is not so high; not only so, but the crop requires to stand in stook rather longer before it is ready for stacking. Early cutting gives straw of higher value for fodder purposes as it retains more nutriment, but, unless in special circumstances, that does not compensate for the diminished yield of grain that would result from too early cutting.

In deciding as to whether oats are at the right stage for cutting, attention should be paid to the colour of the crop and the condition of the grain. The crop should be cut when there is a nice uniform yellowish colour all over, but just before the greenish tinge has gone entirely. The straw below the neck should be changing to yellow at that time, and that is a further fairly reliable indication that the crop is ready for cutting. The grain again should be well filled and fairly firm, but not quite hard. Cut at that stage, the ripening process is completed in the stook, a high yield of grain is obtained as it is not so readily lost in handling, and the straw not being over-ripe is of higher feeding value and makes very much better fodder.

When there is an extensive area to deal with it is practically impossible to cut the entire crop when it is just at the right stage, but it is a wise precaution to start harvesting operations early rather than late.

The busy harvest season commences with the cutting, and till the last sheaf has been secured there is as a rule but little respite for the harvesters. The scene in a typical harvest field to-day is totally different from what it was about half a century ago. For the actual cutting the sickle or hook and the scythe have had to give place to the reaping-machine, and that in turn to the binder, which has been greatly improved, so much so, indeed, that it is difficult to see what further improvements

are possible. In recent years tractors have in many cases been used to replace horses, and many binders with wider cutting-bars have been introduced. In other cases two ordinary binders have been attached to a single tractor, the one being placed a little behind the other.

The binder is now very widely used, and it is only on the smallest farms that it does not form a regular part of the farm equipment. Though that is the case, the scythe is still necessary for opening up fields, for making roads round sections, for rounding corners where the binder is attached to a tractor, and for taking out parts where the crop has been badly twisted and laid. The reaper is still used on many of the smaller farms, the crop being lifted and tied by hand. It is also frequently used for cutting the crop on very steep ground, and for dealing with very short or very badly laid crops, and under such conditions it does better work than the binder; but, wherever conditions are suitable, cutting with the binder is by far the most expeditious and satisfactory method of dealing with the crop. It is certainly one of the best labour-saving machines ever introduced, and its introduction has greatly simplified harvesting operations. It is on nice standing crops that the binder does its best work, and on such, with a team of three active horses and a cutting bar of at least 5 ft. in width, from $1\frac{1}{3}$ to $1\frac{1}{2}$ acres can be cut per hour. The binder will also do quite good work with crops that have been laid, provided they are not too flat and can be cut against the direction in which they have fallen. If part of the crop is lying away from the cutting bar, such parts should either be turned back or cut out with the scythe. The turning back is rather speedier than cutting out, but in the process a good deal of the grain usually falls out, especially if fairly ripe, and for badly laid and twisted corn it is better to use the scythe.

When cutting one way about $\frac{2}{3}$ or at most $\frac{3}{4}$ of an acre represents a very good hour's work.

The crop should be quite dry when it is cut, for if tied into sheaves in a wet condition it requires to stand much longer before it is in a fit state for leading, and in unfavourable harvest weather the grain sprouts very much more readily. The sheaves should not be too firmly tied, as that prevents them drying so quickly, particularly in the region of the band, and also encourages sprouting in bad weather.

A nice size of sheaf is one of about 30 in. in circumference at the band. It is not advisable to make them larger than that, for though big sheaves effect a saving in binder twine they do not dry so quickly as smaller-sized sheaves.

After the cutting the sheaves should be stooked immediately, and stooking is unfortunately in too many cases a kind of lost art. The great advantages of good stooking are always very apparent if the harvest weather is not of the best. The stook may contain four, six, eight, ten, or twelve sheaves, a common size being ten sheaves, five on either side.

The sheaves are set up in pairs, being firmly planted on their "butts", which should be about 12 to 18 in. apart according to the length of the sheaves, the longer sheaves being placed wider apart at their base. The heads of the sheaves are brought firmly together; they form the apex of the triangle, and are placed in such a way that the rain runs off, instead of into, the sheaves.

The first pair of sheaves set up should form the central pair, and the remaining pairs should be placed at either end and should lean slightly towards the central pair, which in turn, when viewed from the side, should appear to stand erect. In wet districts the stooks, or "shocks" as they are called in some places, are sometimes hooded in order to keep them drier. The hooding consists in placing two sheaves on the top of the stook in such a way as to run off the rain and prevent the stook from getting wet. Hooding is also very beneficial where winged game are prevalent; for though the sheaves used for hooding suffer badly, the others are fully protected. It is much better to sacrifice a little of the grain from two sheaves in every twelve than to have the whole of the crop badly damaged.

In the process of stooking the direction in which the stooks run should always be carefully attended to, as it makes a great difference in the drying of the sheaves. They should be placed so that both sides of the stook will get about the same amount of sun, as drying will then take place with much greater uniformity than if one side of the stook is better exposed to the sun than the other. The direction of the prevailing wind should also be considered, and the stooks placed so that the wind strikes the end rather than the broadside of the stook. As a general rule, under our climatic conditions, the stooks should run not just due north and south but in a north-east and south-west direction, as that on the whole proves fully best. There are, however, many districts where it is impossible to stook to get full benefit from sun and wind, and in these districts the stooks should be placed in such a way as to get the greatest benefit from whichever is likely to prove the most powerful drying agent.

With a good-going binder and a fair crop three men are required for the stooking, if performed in the manner prescribed, and with very heavy crops four men are necessary.

Another common method of dealing with the crop, especially in wet districts, is to put it into rickles with about fifteen large stooks (150 sheaves) in each, larger or smaller according to the degree of dryness at the time of rickling. The rickling may be done at the time of cutting if the crop is fairly ripe and cut in a perfectly dry condition, but very often it stands in stook for some days before being rickled. In these small rickles the sheaves are arranged with the butts to the outside, and the heart or centre must always be kept well up, so that the sheaves really lie in a slanting direction, the head of the sheaf being higher than the butt. The top is finished by opening two or three sheaves, tying these firmly together

at the heads, and spreading out the sheaves in such a way as to completely cover the top of the small rickle and make it just as secure as if it were thatched. The tops should always be tied firmly down with ropes, otherwise they are apt to be blown off in very windy weather.

The crop, if in stook, is generally ready for leading in about ten or fourteen days if cut dry and ripe and if the weather has subsequently been favourable. Sheaves with a good deal of grass in the butts dry much more quickly if changed on to fresh ground after standing about a week. If that is not done they should be turned over, and the butts exposed to the sun and wind for some hours before leading. Unless sheaves are perfectly dry at the time of leading, not only on the outside but also in the heart, heating is sure to result, and that should always be avoided, as it lowers the value of the produce very materially.

In some cases the crop is stacked in the field, the most common type of stack being the round, though the oblong is also favoured by many. In others it is carted home to the stackyard and stacked there, or may even be stored in a large grain shed or Dutch barn. For storing in sheds the sheaves must be even drier than is necessary for stacking in the open, as heating takes place more readily in sheds. In grain sheds the risks of heating are reduced if the sheaves are put up in narrow sections with a minimum of hearting, but the centre must always be kept well up.

Stacks are often built on special rick stances, which have the advantage that they allow free circulation of air all round the stack and also prevent the entrance of rats, which at times do great damage. In other cases the stacks are built on good firm ground with a bottom of ashes, hedge trimmings, branches, or stones covered with a layer of straw, but the stones in particular too often form a harbour for rats.

The diameter of circular stacks in Scotland usually ranges from 9 to 15 ft., but in wet, late districts it may be even less than 9 ft. In the drier regions in the south the diameter is usually much greater. In stack building it is specially important that the centre be firmly built and kept well up. This keeps the heads of the sheaves higher than the butts, and in that position heating does not take place so readily; moreover, there is not the same chance of the stack getting wet, as the rain runs off instead of into the stack. Sometimes triangular " bosses " form the centre of the stack. These may be 3 to 4 ft. wide at the bottom and 6 to 9 ft. in height. They keep the centre well up, permit of rather better circulation of air, and render possible the stacking of sheaves not just quite dry. In other cases central posts are erected, and the stack built round and on these. These also prove very useful in keeping up the centre and in reducing the risks of heating. More frequently, and particularly if the sheaves are in good condition, central posts and bosses are dispensed with, and it is certainly much better when the crop can be secured in such condition that there is no need for these.

In wet districts, and in adverse harvest weather, drying racks or grain-drying sheds are of great advantage, as a section of the crop can be carted just after cutting and put into the rack for drying. The sheaves dry very quickly in the rack, and as soon as they are in fit condition they can be removed and stored and the rack again filled up. In this way the whole crop can be secured in good condition even though the weather is far from favourable. These drying racks and sheds are specially valuable for farms in wet and late districts with a large acreage of grain, and, though they may in one sense entail extra work in handling the crop, they ensure the securing of it in good condition.

When the leading is finished, if the crop is not stored in large grain sheds, thatching is the final step, and that is work which requires to be carefully done. Well-built stacks are easily thatched, but it is more difficult to keep badly built stacks perfectly dry. Wheat straw makes excellent thatch, but both barley and oat straw may be used. In districts where rushes are plentiful they may take the place of straw, and if long and clean they make quite good thatch; but stacks thatched with rushes never have quite the same nice, pleasing appearance.

After a sufficient layer of properly drawn thatch has been put on, it is tied firmly down to keep it in position, and the stacks are then finished off by cutting the loose ends of the thatch, which should protrude beyond the eaves far enough to throw the rain clear, and by trimming the sides of the stack. Well-built stacks " grow " a little from the base to the eaves, and when thatched the trunk is very easily kept dry. Stacks that are just the same width at the eaves as at the base are not so easily kept dry in the trunk, for, unless they are standing quite straight, the drip from the thatch falls on to the sheaf butts at certain places. For that reason the stack should always be widest at the eaves and taper gradually to the base.

The type of farmer can as a rule be fairly well determined from the appearance of the stackyard when the harvest is over.

THRESHING

In some cases a considerable part of the crop is threshed direct from the stook, and when possible this saves a great deal of labour and is a speedy way of clearing the ground; not only so, but the highest yield per acre is generally got by this method, as loss is reduced to the minimum. In other cases the crop is not carted direct to the threshing-mill, but put into oblong or round stacks at a convenient place for threshing, and dealt with as soon as the harvest is over. As a rule stacks to be threshed at an early date are not thatched. For the most part, however, threshing proceeds during the winter just as the grain and straw are required, and this is fully the best method on the average farm, and permits of the chaff, short straw, and light grain being used to greater advantage.

The very marked progress that has taken place in connection with the cutting of the oat crop has already been referred to, and the development associated with the threshing is equally noteworthy. The flail, once so well known, is rarely heard of now, though still used to a very slight extent. It proves useful where only a small quantity of oats has to be dealt with, and where it is necessary to keep the sample perfectly pure, as in the raising of new varieties; but for threshing in general it is now of no consequence. The small threshing-machine for hand power was never widely used at any time, and it also is seldom seen nowadays. On many of the smaller farms horse power was relied on for the driving of the threshing-machine, and still is to some extent, but oil-engines have in many cases taken the place of horses, a very great number having been introduced during the last decade. Under favourable conditions electric power has been made use of in the same connection, and where available proves very valuable. Water power is still preferred on many farms, and where there is a plentiful supply it is a source of power with undoubted merits, as the running costs are practically nothing. Tractors fitted with driving pulleys are gaining fast in popularity as a source of power for threshing purposes. Like the ordinary steam-engine, they are portable, but they may be and often are used for driving a threshing-machine in a fixed position, and this combination of tractor and fixed threshing-machine is replacing the ordinary steam thresher to a considerable extent.

On many farms, however, the great bulk of the crop is still dealt with by the ordinary portable steam thresher, which is obtained from time to time as required.

In the actual threshing the most marked developments have been in connection with the feeding of the threshing-mill, in the dressing of the grain, and in the methods of dealing with the grain, the straw, and the chaff. In this connection many admirable labour-saving devices have been introduced.

There are, of course, very great differences in the capacities of the different threshing-machines, many of those on the smaller farms being capable of dealing with no more than 20 bushels per hour, while several of those on the larger farms may put through 60 to 80 bushels per hour. The ordinary portable steam threshing-machines, and many of the fixed type now seen on the larger farms, are capable of threshing at the latter rate, but there is always considerable variation according to the variety of oats grown and the relative amounts of straw and grain.

YIELDS PER ACRE

There is considerable variation from year to year in the yields of oats per acre according to the season, but soil, variety grown, time of

sowing, manurial treatment, and similar factors are also responsible for bringing about great variations in yield in any single season. In actual practice the yield may vary from 20 bushels per acre, or even less, to over 100 bushels, the highest authentic yield per acre recorded so far being 121 bushels. With good farming, and on fairly good land, yields of from 60 to 80 bushels per acre can readily be obtained, but on medium soils 48 bushels per acre represents a good crop. The average yield per acre obtained in this country at the present time is far short of these figures, and is undoubtedly considerably below what might be termed *maximum profitable production*, which should really be the producer's goal; and judicious manuring alone would, in the majority of cases, bring about a considerable improvement in that respect. The following table gives the yields for 1920 and the three preceding years, also the averages for the ten-year periods 1908–17 and 1898–1907.

	1920. Bushels.	1919. Bushels.	1918. Bushels.	1917. Bushels.	1908–17. Bushels.	1898–1907. Bushels.
Scotland ..	40·0	38·2	41·5	41·8	38·9	36·4
England ..	39·1	35·6	41·9	39·0	39·8	42·0
Wales ..	28·9	34·8	36·7	34·1	34·9	34·6
Ireland ..	40·3	48·7	52·7	53·0	50·4	46·3
United Kingdom	39·1	39·9	44·5	43·7	42·1	41·4

These average yields per acre obtained in the British Isles, and more particularly those of recent years, compare very favourably with the average production in other countries. The yield for Ireland is amongst the best recorded; the average for the United Kingdom, however, is below that formerly obtained in Belgium, the Netherlands, Switzerland, and Germany, chiefly for the reason that the intensity of fertilizer consumption per acre in these countries is greater than that of the United Kingdom.

The table on p. 183 gives the average yield of oats per acre in several other countries in the northern hemisphere for 1919 and 1918, and for two five-year periods 1913–17 and 1908–12.

BUSHEL WEIGHT OF OATS

There is not only great variation in the yield of oats per acre, but there is also marked variation in the weight per bushel. This ranges from under 30 lb. in exceptional cases to little short of 50 lb. in the case of ripe, plump, well-dressed oats. Different standard bushel weights are adopted in practice, and, in consequence, there is apt to be some confusion at times. For the purpose of statistics the bushel is taken as

	1919. Bushels.	1918. Bushels.	1913–17. Bushels.	1908–12. Bushels.
Belgium	40·2	—	—	56·8
Netherlands ..	—	43·1	48·5	53·6
Switzerland	39·8	48·8	50·8	40·4
Germany	34·4	—	—	44·0
Denmark	40·6	36·3	38·8	43·2
Norway	36·2	39·3	37·9	—
Japan	37·9	35·1	35·4	36·1
Sweden	35·7	26·1	32·2	32·6
Luxemburg	—	25·1	32·6	35·8
Austria	—	—	—	28·8
Canada	23·0	24·9	31·5	29·7
United States ..	28·5	28·1	26·7	25·9
France	20·3	21·5	2·7	30·2
Italy	25·2	30·3	22·4	24·6
Algeria	16·3	—	20·4	23·8
Tunis	22·3	23·1	18·1	25·0
Roumania	20·3	—	23·1	21·0
Spain	16·9	16·6	18·8	18·9
Russia (in Europe) ..	—	—	—	17·4

39·3 lb., but for other purposes 39 lb., 40 lb., and 42 lb. are often taken as representing the weight of a bushel; 39 lb. is the figure adopted in the Corn Returns Act (1882), but in the Grain Prices Order, when in force, 42 lb. was taken instead. In actual practice 42 lb. is the standard most commonly adopted, the quarter (8 bushels) being taken as 336 lb. The intermediate figure of 40 is also frequently employed, especially in the seed oat trade, the quarter in that case being 320 lb. and the boll (6 bushels) 240 lb.

On good land the natural bushel weight is generally well over 42 lb., and in the case of well-dressed or well-winnowed oats grown on such land 44 to 46 lb. is not at all uncommon. Weight per bushel is important, and the higher it is the more valuable are the oats, as a given weight of grain of high natural bushel weight will produce more meal than the same weight of grain of lower natural bushel weight.

YIELD OF STRAW PER ACRE

There is not quite the same marked variation in yield of straw per acre as in yield of grain, and this frequently lies somewhere between 25 and 35 cwt.; but, though perhaps less marked, variation does take place according to season, soil, variety, and similar factors. Oats that tiller very freely, as is the case with straw-producers such as Sandy, Tam

Finlay, or Blainslie, are capable of giving the greatest weights of straw per acre, being superior in that respect to the grain-producers, the majority of which tiller very little. The fact, however, that these grain-producers are grown mostly in the better classes of soils or on land that has been manured (thus ensuring a good crop), and the straw-producers on the poorer soils, makes the actual variation in yield of straw per acre less than would otherwise be the case.

COST OF GROWING THE OAT CROP

In many respects the cultivations for the oat crop are of the simplest possible nature, and consequently the cost of growing is not high when compared with certain other crops. At the same time the cost at the present day is about twice what it was prior to 1914. It varies to some extent according to whether the crop is taken after grass or lea, after roots, or after another cereal crop, also according to such factors as cultivation required, manures applied, weather during harvest, &c., but the following estimate includes the principal items chargeable against the crop, and gives an indication of the approximate cost per acre at current rates for an area of not less than 40 acres in extent. In the estimate no allowance has been made for management or for interest on capital. For full information on cost of growing see article on COST OF PRODUCTION OF GRAIN CROPS.

ESTIMATE OF COST OF PRODUCTION PER ACRE

	£	s.	d.
Proportion of rent, rates, taxes, and insurance	1	12	6
Ploughing	1	5	0
Harrowing or cultivating	0	8	0
Artificial manures and cost of application, 2 cwt. superphosphate, 1 cwt. potash salts (30 per cent), 1 cwt. sulphate of ammonia (unexhausted portion not charged)	1	7	0
Seed oats, 6 bushels at 5*s.* per bushel	1	10	0
Drilling in seed	0	3	0
Harrowing	0	2	0
Rolling	0	2	0
Weeding and spraying where necessary	0	8	0
Opening up; cutting and stooking	0	16	0
Stacking and thatching	1	0	0
Threshing and dressing grain	1	0	0
Marketing	0	6	0
Proportion of general expenses; implements, machinery, use of buildings, share of liming expenses, &c.	0	17	6
Residual fertility from previous crops	0	14	0
	11	11	0

VALUE OF PRODUCE

In very many cases the entire produce of the oat crop (grain and straw) is consumed on the farm on which it is produced, but in other cases a considerable amount of the grain is marketed, also part of the straw if not required for fodder. The average market price of oats in England and Wales, per quarter of 312 lb., as determined under the Corn Returns Act (1882), may be taken as representing fairly approximately the average annual price in the United Kingdom, and for the period 1909 to 1920 this has been as follows:

	1910.		1911.		1912.		1913.		1914.		1915.		1916.		1917.		1918.		1919.		1920.	
	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d
Price per Quarter	17	4	18	10	21	6	19	1	20	11	30	2	33	5	49	10	49	4	52	5	56	10

The very marked rise in price in 1915 and the subsequent high prices were brought about entirely by war conditions, and but for the sale of oats, other than those for seed purposes, being controlled by the fixing of maximum prices, these would undoubtedly have soared much higher.

With regard to straw the average market price per ton for first quality straw was as follows:

	1914.		1915.		1916.		1917.		1918.		1919.		1920.	
	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.
Scotland ..	43	6	60	9	84	4	66	3	81	0	91	0	—	
England ..	44	0	55	0	87	0	76	6	103	0	120	0	158	0

COMPOSITION OF PRODUCE

There is considerable variation in the composition of oats according to the variety and the conditions under which they are grown and harvested. Some of the older varieties of the straw-producing type are a little richer in oil than many of the grain-producers, and they have a thinner husk; consequently the proportion of husk to kernel is rather smaller. On the average this amounts to about 25 per cent, but may vary from as little as 21 to as much as 29 per cent.

There does not appear to be any very material difference in the composition of the straw of different varieties, the greatest variation being according to the degree of ripeness at the time of cutting. For fuller information see article Products of Oats.

UTILIZATION OF THE OAT CROP

Oatmeal.

Part of the grain produced is made into meal, which is fairly widely used for human consumption, more particularly in Scotland. Its use for stock feeding is restricted on account of its relatively high cost, but for calf feeding it is, in spite of its high cost, favoured by many feeders because of the satisfactory results which attend its use. It is also very valuable for pig feeding, being little behind barley meal, and, in the form of pin-head oatmeal, it is used to a considerable extent for chicken rearing.

Oat Grain.

Oats, either in the form of whole or crushed oats, are very widely employed for stock feeding, and, all things considered, are the most highly valued of the home cereals for feeding to farm stock. Apart from the actual nutriment they contain, and the fact that they are easily digested, they generally have a specially beneficial effect, due possibly in great measure to the husk associated with the grain stimulating the flow of digestive juices.

For horses, oats constitute the staple food, and for animals in heavy work particularly it is impossible to get an equally suitable substitute. They are, moreover, a very safe food, and for that reason alone are often preferred to other foods. New oats, however, are not so suitable for horses, and, though these are often fed, it is very much better to reserve a quantity of old oats for feeding for at least two months after harvesting.

Oats are also very much in demand for sheep feeding, and on many farms a large proportion of the grain produced is used in that way. As part of the ration for fattening hoggets or for lowland ewes nursing lambs they are specially valuable.

Oats may also be profitably utilized in the feeding of all classes of cattle. For calves a ration consisting of separated milk and crushed oats has been shown in numerous experiments to give results practically as good as those attending the use of whole milk, and at an infinitely cheaper rate. For young growing stock crushed oats can also be used to good advantage, but for such they should be fed along with foods rich in digestible protein, such as white-fish meal, decorticated earth-nut cake, decorticated cotton cake, soya-bean cake, &c. The same holds good for fattening cattle, also for the feeding of dairy cows, and in numerous cattle-feeding experiments excellent results have been obtained from feeding a concentrated ration one half of which consisted of crushed oats. The successful utilization of oats in the feeding of stock necessitates the use along with the oats of such feeding stuffs as will best make good any deficiencies in their composition.

The relatively low manurial value (18/2) per ton of oats consumed

might be considered, and indeed in some respects is, rather a drawback to their use in quantity for stock feeding, as by their consumption the manure heap is not enriched to the same extent as when the oats are replaced by other feeding stuffs. This is not a serious drawback, however, as in practice the oats are generally used along with foods of high manurial value, the best results being then obtained. In any case it is very easy to make good any deficiencies in the farmyard manure by applying along with it a rather heavier dressing, particularly of artificial nitrogenous manures.

Straw.

Oat straw is by far the most valuable of the cereal straws for fodder purposes, and the great bulk of what is produced is used in that way. As has already been pointed out, the value of straw for fodder purposes depends in great measure on the degree of ripeness at the time of cutting. If the oats have been very ripe before being cut, the straw is neither so nutritious nor so digestible. The straw produced in the moist districts in the west of this country is of relatively higher feeding value than that produced along the east coast, where the rainfall is lower.

Straw generally forms part of the fodder for ordinary farm horses during the winter, but it is not specially suitable for that class of stock, and should always be replaced by hay when the heavier spring work commences. For dairy cows on farms where little hay is grown it is relied on as the main source of fodder, and even where hay is available it generally constitutes a considerable part of the fodder ration. For fattening cattle it is very widely employed; indeed winter feeding is rarely attempted on a large scale unless there is a plentiful supply of oat straw. It is also widely used as fodder for young cattle, but is not so suitable for calves and very young stock, and wherever possible the fodder for these should consist of hay.

Apart from the utilization of straw for fodder purposes a very large quantity is used for bedding or litter, particularly on farms where the winter fattening of cattle is practised, and in this way a large amount of manure is produced and the fertilizing ingredients returned to the land. To get the best results from oat straw as litter it should, particularly when the supply is limited, be used in conjunction with peat moss, as that is much more absorbent than the straw and the resulting manure is more concentrated.

Oat Hay.

Sometimes the oat crop is cut before it begins to ripen and is made into hay. To obtain the best results the cutting should take place just after the oats have shot full out and at the beginning of the actual ripening period. If the cutting takes place at that stage, and if the crop is con-

verted into hay under favourable weather conditions, a valuable, bulky, nutritious fodder is obtained, which can be successfully fed to all classes of stock.

The growing of oats for the making of oat hay is little known in this country, but it is a common method of utilizing the crop in parts of America and in South Africa. It has, however, been found that, when used as the sole source of fodder, trouble is likely to arise on account of the large amount of phosphoric acid, relative to lime, present in the hay, and it has accordingly to be fed with a certain amount of care.

Oats may also be grown as a forage crop and cut green for soiling, and for that purpose they are very valuable. By successive sowings and stimulation of the crop by judicious manuring, the green produce can be available over a fairly long period, for the crop remains in a succulent state till the ripening is well advanced.

Though the oat crop may be used alone for hay or for green forage, its value for either of these purposes is greatly enhanced by growing it in mixture with vetches or peas, as these leguminous crops add to the yield and give produce of superior feeding value.

For the making of ensilage the oat crop has also considerable merits, and it may be profitably utilized in that way either when grown alone or in mixture with a leguminous crop. In late and wet districts where, owing to bad harvest weather, there is often great difficulty in securing the crop in good condition, its conversion into ensilage has many advantages and is worthy of more consideration than it receives at the present time.

PRODUCTS OF OATS

By Professor R. A. BERRY, F.I.C., F.C.S., Agric. Dip.(Cantab.).

Under this heading are included the oat grain, oatmeal, and the by-products (oat offals) produced from the grain in the manufacture of oatmeal. The proportion by weight of the principal organs, with the exception of the root of the oat plant at harvest time, may be represented as follows:

Straw	52·0 per cent
Kernel	32·0 ,,
Husk	11·7 ,,
Chaff	4·3 ,,

Grain.

Oat grain consists of a kernel with a husk (pale) attached. A small proportion of the husk becomes detached from the kernel in the process

of dressing the grain. In consequence average samples of dressed grain are found to contain anything up to about 4 per cent of shelled grain, although individual samples may sometimes contain as much as 15 per cent. In addition, there is often present a small proportion of weed seeds, chaff, &c. In the case of imported oats the weed seeds present provide a means of identification of the country of origin.

The grain in the ear is borne on spikelets, and each spikelet consists of either a single grain (singles) or a pair of grains (doubles), or grains in triplets or quadruplets, &c. The component grains in a spikelet vary in size, composition, and in the proportion of husk to kernel, as shown in the following figures:

	Singles.	Doubles.	
		Firsts.	Seconds.
Kernel, weight of 1000 grains (grammes)	21·4	27·6	14·0
,, percentage in grain	73·1	73·3	79·7
Protein in dry kernel (percentage) ..	15·37	15·18	14·5
Oil ,, ,, ..	9·21	8·63	9·09
Proportion by weight in ear, e.g. Potato oat	62·9	26·8	10·3

The smaller grains, such as the seconds of the "doubles" and the thirds of the "trebles", are partly winnowed out in the dressing of the grain and go to form the "light corn". It follows, however, that uniformity in a sample of grain, both as regards size and chemical composition, will depend upon the relative proportion of singles, doubles, &c., in the spikelets. The light corn averages between 7 and 10 per cent of the total yield of grain, although it occasionally amounts to as much as 20 per cent.

The kernel differs entirely in composition and nutritive value to that of the husk, as shown in the following average analysis. For the purpose of comparison, the composition of the grain of oats and wheat is included in Table I below:

TABLE I

	Oat.			Wheat.
	Kernel.	Husk.	Grain.	
Moisture ..	13·40	6·77	13·40	13·4
Protein	12·24	2·45	9·46	12·1
Oil	7·73	1·27	5·33	1·9
Carbohydrates ..	63·47	52·20	60·23	69·0
Fibre	1·33	33·45	8·96	1·9
Ash	1·83	3·86	2·62	1·7

From the above figures it is seen that the protein and oil are contained almost entirely in the kernel, whilst the husk contains the bulk of the fibre. This fact explains one of the principal differences in composition, namely the fibre content, between the grain of oats and that of other cereal grains which include the kernel only, such as wheat. In the former the percentage of fibre is about 9·0 and in the latter 1·9.

The husk, like other plant organs, varies in composition according to the stage of growth; for example, in the newly formed grain the husk contains about 6·2 per cent of protein matter, and in the mature grain only about 2·4 per cent. The proportion of fibre increases as maturity is reached. In addition, the husk varies in composition according to the variety of oat. For example, taking the varieties as a whole, the protein is found to vary from 1 to 3 per cent, the fibre from 30 to 36 per cent, and the ash from 4·5 to 5 per cent. For complete analysis of the husk see Oat Offals, p. 196.

The proportion of husk in the grain is an important factor, and must be taken into account in connection with the valuation and utilization of the grain, either (1) for feeding purposes or (2) for the production of oatmeal.

The husk, in different varieties and under different cultural conditions, varies from about 21 to 29 per cent of the total weight of grain. When the proportion forms 25 per cent or under, the grain is considered to be thin husked, and thick husked when the proportion reaches 28 per cent or over. The proportion diminishes as the size of the grain increases, as shown in the following figures:

Weight of 1000 Kernels (Grammes).		Husk in Grain, per Cent.
24·01	....	24·26
27·67	....	24·05
31·58	....	23·35

This applies not only to the size of the grain as affected by cultural conditions, but to grain from varieties of similar parentage. The percentage of husk in some of the principal varieties of oats is shown in Table II. The varieties are grouped into (*a*) grain producers and (*b*) straw producers.

The Kernel.

1. **Composition.**—The nitrogen constituents of the kernel consist almost entirely of proteins, and which are similar to those contained in wheat and barley. About 15 per cent of the total protein is soluble in water, and on boiling a water extract of the kernel a flocculent precipitate of albumen separates. The average percentage of protein in Scotch oats is 12·3 per cent, and for oats grown in England the average generally

TABLE II

Variety.	Weight of 1000 Grains: Grammes.	Percentage Kernel in Grain.	Composition of Grain: Percentage.					
			Moisture.	Protein.	Oil.	Carbohydrate.	Fibre.	Ash.
A. Grain Producers								
Abundance ..	40·9	76·2	13·5	9·05	4·77	61·58	8·56	2·54
Banner.. ..	21·96	75·2	13·5	9·68	5·65	59·47	9·01	2·69
Beseler.. ..	36·8	75·7	13·5	8·86	5·30	60·83	8·91	2·60
Black Bell ..	35·4	72·9	13·5	7·82	5·92	60·27	9·91	2·58
Black Mesdag	28·7	72·3	13·5	11·45	5·32	56·84	10·07	2·82
Black Tartarian	31·5	73·1	13·5	9·27	4·41	60·39	9·67	2·76
Bountiful ..	44·7	73·5	13·5	11·14	3·79	59·12	9·72	2·73
Crown	42·2	75·4	13·5	11·15	4·41	59·32	8·95	2·67
Golden Rain ..	35·3	78·0	13·5	9·87	4·68	61·52	7·94	2·49
Hero	40·8	73·4	13·5	11·11	4·69	58·23	9·68	2·79
Leader.. ..	37·3	72·5	13·5	8·15	5·90	60·10	9·79	2·56
Mounted Police	33·8	76·0	13·5	8·46	5·12	61·66	8·68	2·58
Newmarket ..	33·1	76·1	13·5	9·59	5·27	60·36	8·65	2·63
Record.. ..	38·4	72·3	13·5	7·86	5·40	60·80	9·82	2·62
Storm King ..	41·9	72·8	13·5	11·36	3·98	58·79	9·57	2·80
Supreme ..	38·8	73·1	13·5	9·97	5·20	58·89	9·77	2·67
Tartar King ..	44·0	72·8	13·5	11·42	4·00	58·73	9·62	2·73
Victory ..	38·2	76·2	13·5	8·43	4·69	62·41	8·45	2·52
Waverley ..	35·5	75·9	13·5	8·82	5·04	61·33	8·76	2·55
Wideawake ..	36·5	75·0	13·5	8·87	4·97	60·9	9·11	2·65
Yielder ..	42·7	71·9	13·5	10·27	3·78	59·9	9·85	2·70
B. Straw Producers								
Birlie	28·1	76·2	13·5	9·59	5·76	59·84	8·69	2·63
Black Winter ..	41·7	78·9	13·5	8·84	6·61	60·62	7·92	2·51
Blainslie ..	30·8	75·7	13·5	9·86	6·12	58·89	8·88	2·75
Clemrothry ..	28·5	75·3	13·5	9·53	6·09	59·15	9·03	2·70
Early Fellow ..	28·6	75·3	13·5	9·73	6·01	59·06	9·03	2·67
Friesland ..	29·5	74·6	13·5	9·34	6·06	59·1	9·27	2·73
Hamilton ..	28·8	75·6	13·5	9·93	5·90	59·11	8·91	2·66
Longhoughton	27·4	76·5	13·5	9·74	6·08	59·45	8·58	2·65
Potato	29·8	75·4	13·5	9·40	5·97	59·42	9·03	2·68
Sandy	26·3	76·7	13·5	10·44	6·02	59·15	8·25	2·64
Tam Finlay ..	29·2	75·5	13·5	9·38	6·33	59·25	8·86	2·67

For a comparison of the composition of oat kernel and grain, see Table I.

given is 10·3 per cent. The fatty substances which form a characteristic constituent of oat grain are composed of an oil which amounts to about 70 per cent of the total; the remainder consists of fats. In addition, there is present about 1·25 per cent of a lecethide, a substance closely allied to fats. A compound of the nature of an alkaloid, to which the name "Avenin" is given, is also said to be present. Its presence is said to partly account for the beneficial effects which the feeding of oats seems to exercise, over and above that produced by the ordinary nutritive substances present. The favourable effect seems to partake of the nature of a stimulating action upon the secretion of the digestive juices in the stomach and in the intestines. The presence of the husk may, of course, partly account for this effect by producing a mechanical stimulus on the walls of the alimentary canal. The average percentage of oil is 7·73 per cent in Scotch oats, and 4·8 per cent is given as the average for English oats. Starch, as in all cereal grains, forms the principal carbohydrate. The average percentage of carbohydrate is 63·5 and the fibre 1·33. The ash, which forms about 1·83 per cent, is composed of phosphoric acid (P_2O_5) 52·6 per cent, potash (K_2O) 24·8 per cent, lime (CaO) 5·8 per cent, and magnesia (MgO) 11·7 per cent.

The oat plant possesses great powers of adaptability. It is therefore not surprising to find that the composition of the grain, also that of the straw, is subject to considerable variation. As would be expected, and as the following figures show, the composition of the grain changes as it develops.

DRY KERNEL, PERCENTAGES

	July.		August.		
	20th.	27th.	3rd.	10th.	17th.
Dry matter	25·3	38·6	52·0	60·0	65·1
Nitrogen[1]	2·69	2·16	1·89	2·13	1·99
Fat	10·22	11·55	9·75	7·84	7·03
Ash	3·54	2·58	2·33	2·13	2·18
Phosphoric acid (P_2O_5)	1·49	1·21	1·08	1·08	1·14
Potash (K_2O)	1·44	0·91	0·83	0·73	0·68

In addition to the effect of the stage of growth, the principal factors which influence the composition and character of the grain are variety, season, and locality, which includes soil and season; early and late sowing, manuring, &c., exercise comparatively little effect. The characters of the grain which are subject to greatest variation are size and protein content; whilst the oil, ash, water, and proportion of kernel in grain show a

[1] Percentage nitrogen multiplied by 6·25 = percentage protein.

less but yet a considerable variation. The magnitude of the variation due to season, soil, &c., is represented in the following figures, which express in percentages the difference between the grain with the lowest constituent and the grain with the highest constituent, obtained over a period of three years on a large number of farms in the West of Scotland.

	Kernel.		Dry Kernel.			
	Weight of 1000 Grains.	Per Cent in Grain.	Nitrogen.	Oil.	Ash.	Water.
Potato oat ..	31·5	5·9	38·2	23·2	23·3	33·7
Beseler's Prolific	31·4	9·1	59·5	26·1	31·1	32·2

From these figures it is seen that on the whole the old-established varieties of oats are subject to less variation when grown under varying conditions of soil and climate than are the newer varieties.

A growing period round about 140 days seems to indicate conditions of soil and climate most suitable to the production of oat grain and straw of the highest nutritive value. These conditions are typical of large areas in Scotland. They represent a moderate rainfall evenly distributed throughout the growing period, and a temperate climate. This ensures, other things being favourable, a uniform growth and a maximum filling of the grain. With excessive warmth and a deficient rainfall, such as is prevalent in most seasons in the southern counties of England, there is a shorter growing period, and premature ripening often occurs, with the result that the grain is not fully developed and there is a thicker husk. The grain is not of such good quality. A similar result occurs in districts when the rainfall is excessive and the temperature relatively low. Under these conditions the crop is harvested before it is fully ripe, with the result that the grain is not properly developed; it is therefore smaller and is of poorer quality.

2. **Nutritive Value.**—With the exception of the fibre the constituents of oat grain are equally digested by cattle, sheep, horses, and pigs. The constituents are well balanced, and for this reason oats may be used as a food for almost any kind of animal under almost any condition. No food-stuff is perhaps of greater all-round utility than oat grain. As to its value as human food, there is no better evidence on this point than the fact that in early days, and even under certain circumstances at the present time, oatmeal forms the staple food for the population in many parts of Scotland and other countries. Before the Great War about 200,000 tons of grain in the form of oatmeal were consumed as human food in the United Kingdom. About 3½ millions were used as cattle food, which is nearly one-third of the total con-

sumption of concentrated food. This latter figure shows the importance of oats as a cattle food.

The average composition and nutritive value of oat grain is shown in the following figures:

	Per cent Composition.	Per cent Digestible Nutrients.
Water	13·40	—
Protein (crude)[1]	9·46	7·4
Fat	5·33	4·5
Carbohydrates (soluble)	60·23	46·3
Fibre	8·96	2·2
Ash	2·62	—

Nutrient or albuminoid ratio 1: 7·9.
Total digestible energy expressed in terms of starch, 67·6 per cent.

Not only is oat grain of high nutritive value and easily digestible, as is seen from the above figures, but it is very palatable, and, as already indicated, it possesses a special feeding quality of its own, which is not held by other cereal grains. The actual feeding value of the grain will, however, be diminished when the proportion of husk and water respectively is high, compared with a low proportion of each. The amount of water in the grain at harvest time may reach as much as 18 per cent in late districts when the rainfall is high, and as small as about 10 per cent in early districts when the rainfall is low. While in the rick the grain dries to a certain extent, and the average water content of grain about three months after harvest is 13·4 per cent in Scotland. Oats are best fed after they have been in the rick for some time.

As a food for horses, oats are unsurpassed. For fast work it is generally assumed that they cannot be dispensed with. However, by judicious mixing of other foods, such as maize, barley, bran, dried grains, and many other concentrated foods, oats can be partly or entirely replaced without loss of efficiency in the feeding of farm horses and heavy horses generally. This is an important matter, since oats are a relatively costly food. The substitution must be based on the starch equivalent value of the food and not a pound for pound value. On this basis due allowance for differences in nutritive value of the substituted food is made. Oats are fed to horses whole, but it is more usual to give them crushed, as in this latter condition they are more readily digested.

Although horses are the chief consumers of oats, both sheep and cattle do well on them. In some districts oats form the concentrated food usually given to sheep to supplement roots and hay in winter feeding. For cows in milk, oats form a most valuable concentrated food.

[1] 90 per cent is pure protein.

They not only have a favourable influence upon the yield and quality of milk and milk products, but also upon the health of the animal. As a component of a mixture of foods for cows, they are unsurpassed by any other grain. When mixed with other suitable foods, such as linseed cake, crushed oats are used with success as a food for newly weaned calves. They are not commonly used for pigs, probably because of the fibre which they contain, but when given in wet mashes they make an excellent food little inferior to barley.

Imported Oats.

Oat grain is imported into this country from Canada, Argentine, Germany, Danubian provinces, &c. Manitoban oats are large and heavier per bushel than either the Danubian or Plate oats. The main difference in composition between home-grown oats and imported oats is that the grain from the latter is smaller, drier, and contains a thick husk. The protein content is high, while the percentage of oil is about the same as that of home-grown grain. The weight per bushel is low. The following is an average percentage composition of imported oats:

	Plate.	Manitoba.
Weight of 1000 kernels (grammes)	26·03	29·35
Per cent kernel in grain	68·2	72·7
Moisture	11·64	12·48
Protein	10·02	10·29
Oil	5·90	5·45
Carbohydrates	58·55	58·61
Fibre	10·04	9·38
Ash	3·85	2·86
Weight per bushel (pounds)	36 to 38	45 to 46

Oatmeal.—The mealing power of oat grain will vary according to the proportion of kernel in the grain. It is also affected by the water content, the higher the amount of water in the grain the less will be the yield of dry meal. In addition to the meal the other by-products produced are meal seeds, rough seeds, and oat dust.

The following is an average proportion by weight of oatmeal, &c., obtained from a thin- and a thick-husked grain respectively.

	Potato (thin husk).	Storm King (thick husk).
Percentage kernel in grain	76·35	65·82
" yield of oatmeal	58·6	51·5
" meal seeds	2·6	2·6
" rough seeds	19·2	27·9
" oat dust	7·0	7·6

The average yield obtained by millers, using as a rule thin-husked varieties of oats, varies according to the kind of mills used, as shown below.

	Old Stone Mills.	Modern Mills.
Oatmeal	58·0	60·0
Rough seeds	20·0	18·0
Meal seeds	3·0	5·0
Oat dust	7·0	—
Scree dust	—	5·0

The average percentage composition is as follows:

Moisture	8·25
Protein	15·0
Fat	8·25
Carbohydrates	65·25
Fibre	1·5
Ash	1·75

Quality in oatmeal is judged mainly by colour, flavour, water-absorbing powers, and keeping qualities. Freshly made oatmeal contains between 1 and 2 per cent of water. On keeping, water is rapidly absorbed from the air until the water content reaches about 8 or 9 per cent.

Oat Offals.

Rough Seeds, or **Oat Schudes,** are made up of the husk removed from the grain during milling. Their composition is variable, as seen in the following figures:

Moisture	6·0 to 9·0 per cent.
Protein	2·0 ,, 3·0 ,,
Fat	0·7 ,, 2·0 ,,
Carbohydrates	51·0 ,, 56·0 ,,
Fibre	29·0 ,, 36·0 ,,
Ash	3·5 ,, 4·5 ,,

At the present time this product is ground to fine meal and used for mixing with compound and other feeding cakes. It is also used in breweries, for litter, for packing, &c. At one time it was mostly burnt in the kilns. According to the above analysis, this substance possesses more nutritive properties than is commonly supposed.

Meal Seeds consist of the husk along with the kernels of the small oat grains still attached. Their feeding value is variable, and will depend upon the proportion of kernel still left attached to the husk. The composition is indicated in the following figures:

Moisture	6·0 to 11·0	per cent.
Protein	3·0 „ 7·0	„
Fat	1·5 „ 4·5	„
Carbohydrates	45·0 „ 55·0	„
Fibre	20·0 „ 30·0	„
Ash	3·5 „ 4·5	„

It is of better feeding value than the rough seeds, although, like the latter, it still contains a large proportion of fibre.

Oat Dust.—This substance consists of the dust and small pieces of husk removed in the process of cleaning and milling of the grain. It is variable in composition, light, and dusty. The following is an analysis:

Moisture	6·25 to 9·0	per cent.
Protein	10·0 „ 14·5	„
Fat	9·0 „ 11·5	„
Carbohydrates	45·0 „ 58·0	„
Fibre	10·0 „ 20·0	„
Ash	3·0 „ 4·5	„

It is of better feeding value than the two previous products. As already stated, the oat offals are used mostly as components of cattle foods.

Oat Straw.—This is the most valuable of the cereal straws for feeding purposes, largely due to the fact that oats are usually cut before the crop is dead ripe, and before migration of the digestible nutrients from the straw into the grain is complete. Further, the digestibility of the crude fibre diminishes as straw approaches maturity.

The principal factor affecting the composition of straw is the degree of ripeness at the time of cutting. Early cutting gives straw of greatest feeding value; the maximum value being attained at the flowering stage. Variety, soil, and manuring have much less effect upon the composition.

The following may be taken as the average percentage composition of oat straw:

	Total.	Digestible.
Moisture	14·0	—
Protein, Crude	2·1	0·7
Oil, Crude	2·2	0·7
Carbohydrates, Soluble	39·6	18·1
Fibre, Crude	37·0	20·1
Ash	5·1	—

For more detailed information respecting the composition of oat grain and straw, the reader is referred to the following paper: "Composition and Properties of Oat Grain and Straw", R. A. Berry, *Journal of Agricultural Science*, Volume X, Part iv, 1920.

BARLEY

By HERBERT HUNTER, B.Sc.

The genus Hordeum, by reason of strongly marked varietal distinctions, is of particular interest to the systematic botanist, the plant breeder, and the student of farm crops. Few cereal crops present such clear contrasts as hulled and naked grain, fertile and infertile florets, awned and awnless grain, pigmented and colourless grain.

All botanical classifications of Hordeum are based on the form of the inflorescence, and for this purpose the following variable characters have been utilized: (1) fertility, (2) adherence and non-adherence of the paleæ (or outer skins) to the caryopsis (or grain), (3) the awn or appendage to the paleæ, (4) colour of paleæ, (5) glumes.

VARIABLE CHARACTERS

1. **Fertility.**—The rachis or axis of the ear of barley is divided into internodes, of which there may be any number up to, and sometimes exceeding, forty. Each internode bears three sessile florets, an arrangement which is repeated on each side of the rachis alternately. Of the three florets, one which is termed the median is always fertile and lies in the same plane as the rachis with its ventral surface facing the rachis. The two remaining florets are termed lateral florets, and the four rows they form, two on each side of the rachis, lateral rows.

The two lateral florets may be fertile, in which case the barley is described as six-rowed, or they may be infertile, when the barley is described as two-rowed. Between these two forms there is an intermediate group, in which the two lateral rows on each side of the rachis are fertile but of smaller size than in the median rows, and usually devoid of awns.

A further group exists in which the lateral florets are still further reduced and frequently represented by a single glume only.

The spike or ear in the whole of the four groups may be short and wide or long and narrow.

2. **Adherence or Non-adherence of the Paleæ to the Caryopsis.**—The caryopsis, or seed, is enclosed by an outer and inner palea, the former terminating in an appendage called the awn. The paleæ may adhere to the seed or may remain detached, as in the case of most varieties of wheat.

3. **The Awn or Appendage to the Paleæ.**—The awns or appendages to the outer paleæ may be lanceolate and from ten to fifteen times the length of the seed, with serrations along both edges, when they are said to be normal; they may be short and terminating in three processes, one of which is recurved and often bearing a rudimentary flower, when they are said to be trifurcate. Again, the awns may be absent, the paleæ terminating in a mere point.

4. **Colour of Paleæ.**—These may be yellow, white, brown, or black. The caryopsis, or seed, itself may also be coloured, the colour in this case being due to colouring matter either in the pericarp or the aleurone layer.

5. **Glumes.**—These occur in pairs outside the outer paleæ and adhere to the rachis at their base. They are attached to the rachis at the same point as the grain, and the normal form is lanceolate in shape, with a short appendage somewhat resembling the awn of the paleæ.

In some forms the glumes of the median spikelets are distinctly awned; in other forms the glumes of both median and lateral spikelets are awnless. Again, the glume may assume an ovate-lanceolate shape with distinct awns.

CLASSIFICATION

Various systems of classifying the different varieties of barley have been used from time to time by different authorities, beginning with Linnæus in 1753, who described six forms of Hordeum (four species and two varieties):

Hordeum vulgare and *H. hexastichum*, six-rowed barley.
Hordeum distichum and *H. zeocriton*, two-rowed barley.
Hordeum vulgare cœleste and *H. distichum nudum*, naked barley.

In 1872 Henze published a new classification based on the examination of a larger number of varieties. This was followed, in 1885, by Körnicke and Werner's system in their *Handbuch des Getreidebaues*,[1] which has been regarded as a standard.

Körnicke recognized four primary divisions of *Hordeum spontaneum*,

[1] *Journal für Landwirtschaft*, 1885.

namely, *H. hexastichum* (six-rowed barley), *H. tetrastichum* (four-rowed barley), *H. intermedium* (intermediate form with lateral spikelets, fertile but diminutive in size), *H. distichum* (two-rowed barley).

In 1885 A. Voss published a system placing all cultivated barleys under the common system *H. sativum*. Voss recognized *H. polystichum*, *H. distichum*, and *H. deficiens* as its sub-species, and pointed out that there was no four-rowed as described by Körnicke.

In 1902 E. S. Beaven[1] published a classification which is undoubtedly the clearest that has yet appeared in the English language. He recognized four sub-species as follows:

1. Spike of six rows of spikelets, all fertile.

   (*a*) Wide with short internodes, *H. hexastichum*, L.
   (*b*) Narrow, with long internodes, *H. vulgare*, L. (*H. tetrastichum*, Kcke.). Both common.

2. Spike of six rows of spikelets, all fertile, two median rows normal, four lateral rows diminutive and without awns.

   (*a*) Wide, with short internodes, *H. intermedium*, Kcke. (var. *Haxtoni*).
   (*b*) Narrow, with long internodes, *H. intermedium*, Kcke. (var. *transiens*). Both rare.

3. Spike with two median rows of spikelets fertile, and four lateral rows infertile or staminate.

   (*a*) Wide, with short internodes, *H. zeocriton*, L.
   (*b*) Narrow, with long internodes, *H. distichum*, L. Both common.

4. Spike with two median rows of spikelets fertile, and four lateral rows rudimentary and without floral organs.

   H. decipiens, Steudel (several Abyssinian varieties).

If all of the forms were represented by wide and narrow forms there would be eight groups or sub-species. No. 4, however, is only narrow-eared in natural varieties, but there is a hybrid wide form. Körnicke's *H. tetrastichum* becomes *H. vulgare*, Beaven recognizing that this form is not a four-rowed barley but a narrow, long, six-rowed form.

Beaven regards the two-rowed barleys *H. zeocrithum* and *H. distichum* as being analogous in the shape of the spike to *H. hexastichum* and *H. vulgare* respectively.

Lastly, he places all varieties in which the lateral spikelets are rudimentary in one group under the name of *H. decipiens*.

[1] *Journal of the Federated Institute of Brewing*, Vol. VIII, No. 5, 1902.

ATTERBERG'S SYSTEM OF CLASSIFICATION APPLIED TO THE SUB-SPECIES HORDEUM COMMUNE

SPECIES		HORDEUM SATIVUM
SUB-SPECIES	Character of appendage to paleæ and of glumes. ←	H. commune; H. macrolepis; H. furcatum; H. inerme
	Colour of paleæ and caryopsis or non-adherence of paleæ to caryopsis. ←	Album; Nigrum; Nudum; Nigronudum
VARIETIES	Fertility. ←	H. polystichum; [H. Rostratum]; H. muticum; H. distichum; H. deficiens
SUB-VARIETIES	Density of ear. ←	H. hexastichum; H. parallelum; H. vulgare; H. zeocrithum; H. erectum; H. nutans
	Character of base of grain. ←	Verum; Spurium; Falsum; Falsum; Verum; Spurium; Falsum; Falsum
	Character of rachilla and dentation of first vein pair of paleæ. ←	A B C D; A B C D; A B C D; A B C D; A B C D; A B C D; A B C D; A B C D

The system of classification largely in use to-day in Germany, Sweden, and Denmark is one described by Dr. Albert Atterberg[1] in 1899. This writer included in his system several distinct characters, which, up to that time, had neither been described nor used by other authorities; and, as a knowledge of the newly described characters is of distinct advantage, indeed almost imperative, to the plant breeder of the present day, a brief description of the system will be attempted.

Atterberg, like Jessen, Körnicke, and Voss, considers all cultivated barleys as belonging to one species, and adopts the botanical name of *Hordeum sativum* for the species as a whole.

He then describes the four following sub-species of *H. sativum*, using the presence or absence and the character of the appendage of the outer paleæ and the size and character of the glumes as his differentiating characters:

1. *H. sativum commune.*—Median spikelets awned. Outer glume small.
2. *H. sativum macrolepis.*—Median spikelets awned. Outer glume of median spikelets large, about as long as the ripe corns (awns excluded).
3. *H. sativum furcatum.*—Median spikelets with trilobate appendage instead of awns. Outer glume small.
4. *H. sativum inerme.*—Median spikelets unawned, having no appendage. Outer glume small.

Each sub-species is then further divided into the four following groups:

(*a*) *Album.*—Fruits brightly coloured, remaining covered by the paleæ on maturity.
(*b*) *Nigrum.*—Fruits darkly coloured, remaining covered by the paleæ on maturity.
(*c*) *Nudum.*—Fruits brightly coloured, the paleæ separating from the fruit on maturity.
(*d*) *Nigronudum.*—Fruits darkly coloured, paleæ separating from the fruit on maturity.

As it is proposed to deal here with some of the commonly cultivated European barleys only, and as these are nearly all white-grained with adhering paleæ, thus coming under *H. sativum commune album*, a detailed consideration of any except this subdivision is unnecessary.

Atterberg then divides each of the sub-species into four main varieties as follows, in this case using the fertility or infertility and the presence or absence of awns on the lateral row of spikelets as distinguishing characters:

H. polystichum, Döll.—All six rows of spikelets with long awns and fertile. Six-rowed forms.

[1] *Journal für Landwirtschaft*, 1899.

H. muticum, Atterb.—The lateral spikelets unawned, fertile and infertile. The pales of the infertile spikelets broad, not lineal. Six- or two-rowed forms obtained by crossing.

H. distichum, Lam.—Lateral spikelets unawned and infertile, their pales small, short lineal. Two-rowed forms.

H. deficiens, Steud.—Lateral spikelets stunted, their pales wanting or almost wanting. Only the small outer glumes present. Two-rowed forms (fig. 7).

Hybrid forms are sometimes obtained corresponding to a variety between *H. polystichum* and *H. muticum*. Such a form, *H. rostratum*, is included in a supplementary manner. In this form the lateral spikelets may be fertile or infertile with very short awns.

The main varieties cannot all appear in every sub-species; for example, in the case of sub-species *inerme*, the main variety *polystichum* is naturally wanting.

In the sub-species *furcatum*, the *polystichum* forms are not normally awned but have trilobate appendages in all the rows. Similarly in the sub-species *inerme* the *rostratum* forms are missing, and the six-rowed forms here belong to the main variety *muticum*.

Each variety is then divided into three sub-varieties, the differentiating character here being the density of the ear, or, as it may be described, the length of the internode of the rachis.

In commerce, barleys of the *zeocrithum* class are referred to as " broad eared " and those of *nutans* as " narrow eared ".

It will be noticed that Atterberg has a similar conception to Beaven in the analogy between *H. hexastichum* and *H. vulgare*, and *H. zeocrithum* and *H. nutans*.

Hexastichum, L. p. p.—Average length of the internodes of the rachis 1·7 to 2·1 mm. Ears therefore very dense (fig. 1).

Parallelum, Kcke. s. l.—Average length of the internodes 2·1 to 2·8 mm. Ears hence of average density.

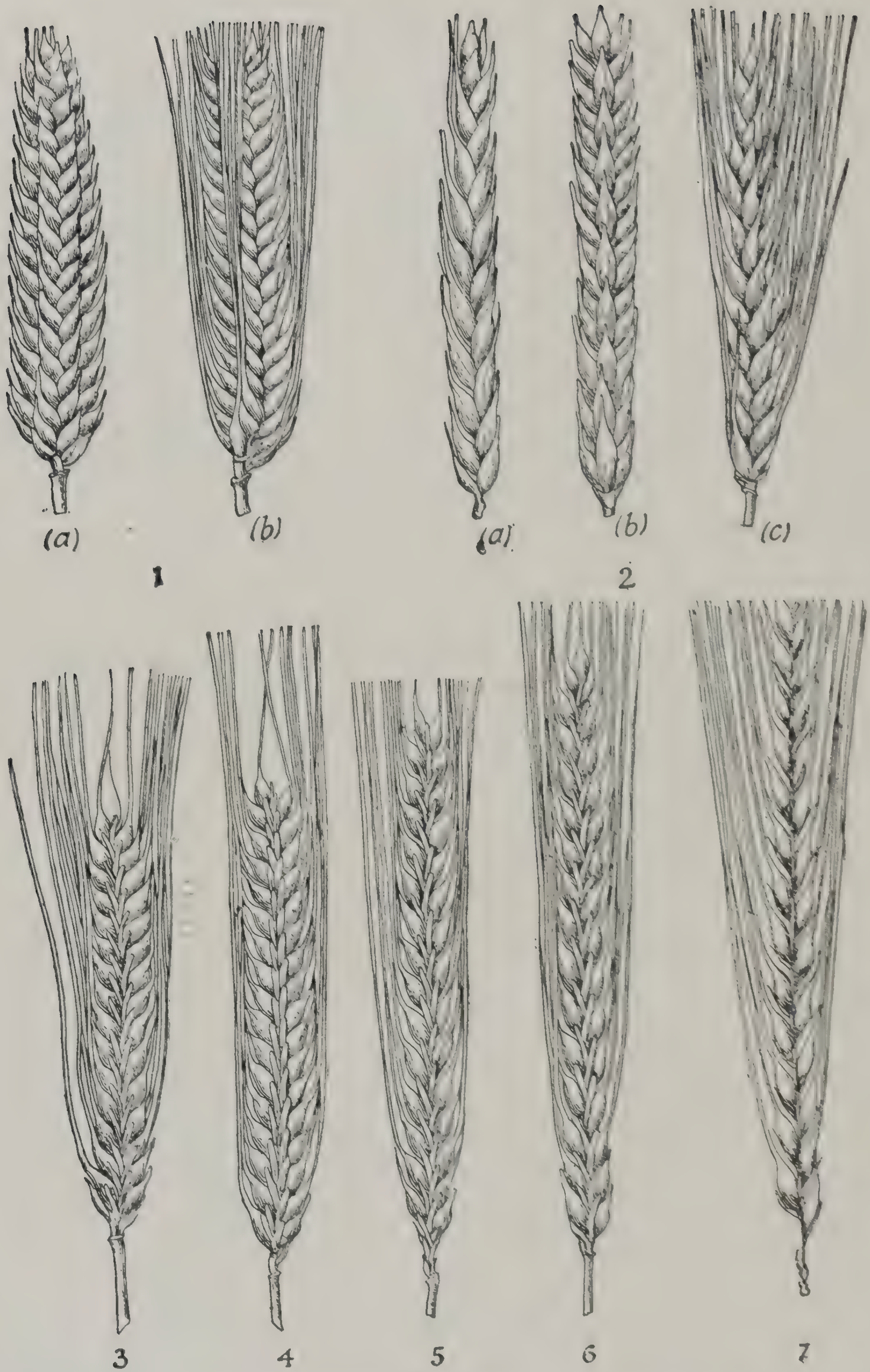
Vulgare, L.—Average length of internodes 2·7 to 4·0 mm. Spikelets hence sparsely set (fig. 2).

The two-rowed barleys are similarly divided into the following sub-varieties:

Zeocrithum, L.—Average length of the internodes 1·7 to 2·1 mm. Spikelets hence very dense (fig. 3).

Erectum, Schubl.—Average length of the internodes 2·1 to 2·8 mm. Ears lax, most drooping on maturity (fig. 4).

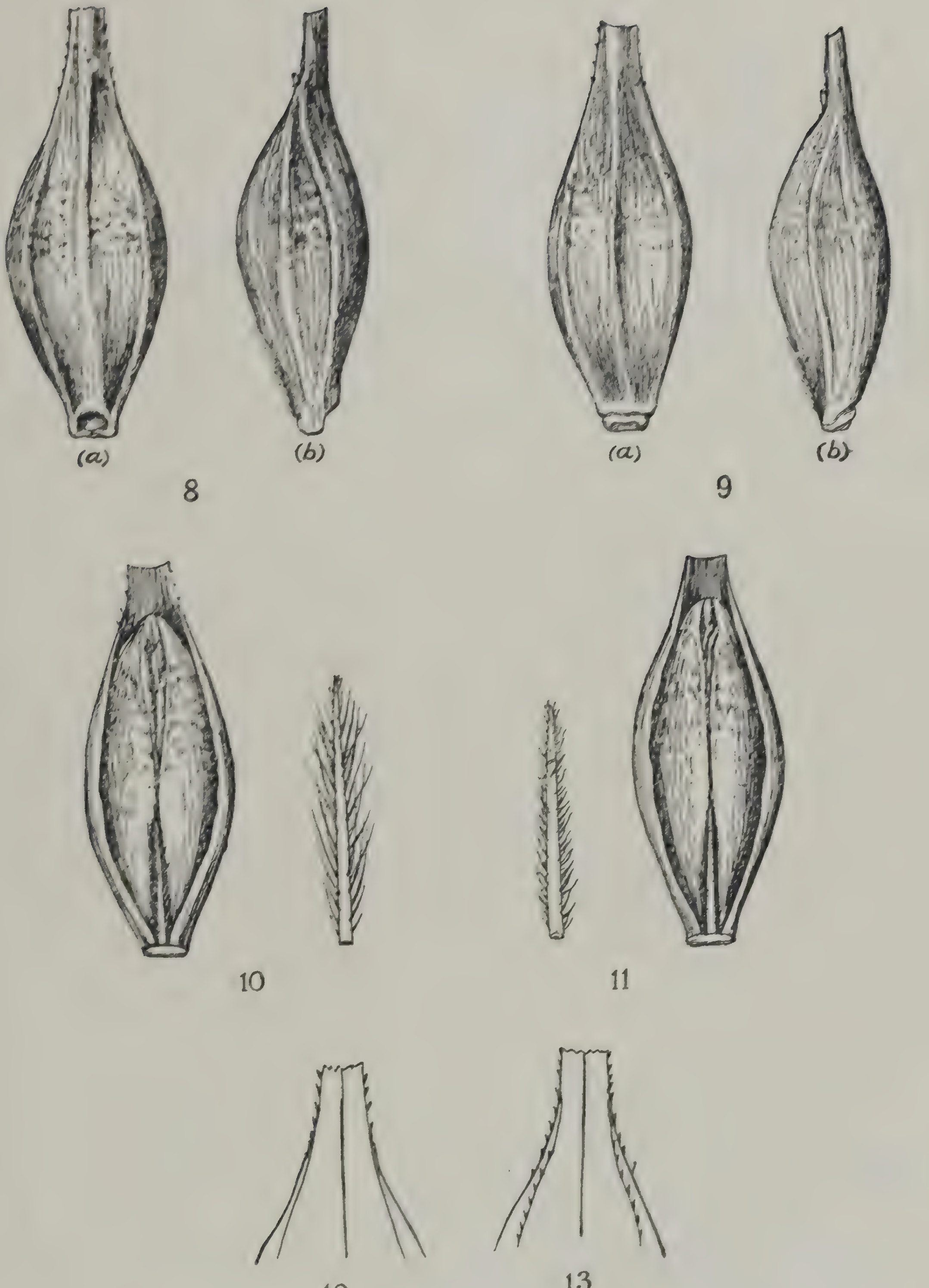
Nutans, Schubl.—Average length of internodes 2·7 to 4·0 mm. Ears lax, mostly drooping on maturity (fig. 6).



Figs. 1–7

1 (*a*), *Hordeum hexastichum*, with awns removed, showing two rows of lateral grains in immediate foreground and two rows of median grains, one at each side of the lateral rows. (*b*), *Hordeum hexastichum*, with awns intact, one row of median grains in immediate foreground. 2 (*a*), *Hordeum vulgare*, with awns removed, showing two rows of lateral grains. (*b*), *Hordeum vulgare*, with awns removed, showing median row of grains with lateral rows, one on each side. (*c*), *Hordeum vulgare*, with awns intact. 3, *Hordeum zeocrithum*—Spratt. 4, *Hordeum erectum*—Goldthorpe. 5, *Hordeum erectum*—Archer. 6, *Hordeum nutans*—Chevallier. 7, *Hordeum deficiens*.

These figures illustrate the gradation of fertility of the lateral florets, from complete fertility in *H. hexastichum* and *H. vulgare* to almost total suppression of the lateral floral structures in *H. deficiens*.



Figs. 8–13

8 (*a*), Dorsal view of grain with a small basal surface. (*b*), Lateral view of the same grain. 9 (*a*), Dorsal view of grain with a distinct basal surface and "nick". (*b*), Lateral view of the same grain. 10, Grain with rachilla in situ and rachilla covered with long hairs. 11, Grain with rachilla in situ and rachilla covered with short fine hairs. 12, Diagrammatic representation of dentation of veins of grain. As rachilla is not shown, this may be form A or C (Atterberg). 13, Diagrammatic representation of dentation of veins of grain. As rachilla is not shown this may be form B or D (Atterberg), the first pair of veins having numerous teeth.

Atterberg realizes, and directs attention to, the considerable variation which may occur in the length of internode in the same form when grown on dry soil and on wet soil, and in dry and wet seasons. He relies to some extent on the shape of the ear, which is characteristic of the sub-varieties, but difficult to define, and, of course, impossible of representation by figures.

Two further divisions, both of which are peculiar to this system, complete Atterberg's classification. He first divides sub-varieties with *densely set ears* in the three following groups, using for this purpose the character of the base of the corn.

Verum.—The base of the corn having a nick (fig. 9).
Spurium.—The majority of the corns without nick and without basal surface.
Falsum.—The base of the corn with a small basal surface (fig. 8).

In the varieties *vulgare* and *nutans* only *falsum* forms are found, for which reason classification into form groups here ceases.

His final division is based on the character of the rachilla and the dentation of the first vein pair of the outer paleæ.

The rachilla (figs. 10 and 11), which is attached to the ventral surface of the base of the corn and to the lodicules which subtend the germ, usually lies in the groove of the grain and has been described as a rudimentary axis. It may be long and covered with short, fine hairs, or short and covered with long hairs. The character and arrangement of the hairs are characteristic of different varieties. Thus they may be long but not extending beyond the apex of the rachilla, or long and extending some distance beyond the apex.

Further, the hairs on the glumes are similar in character to those found on the rachilla. Thus, if long on the rachilla they are long on the glumes, and if short on the rachilla they are correspondingly short on the glumes.

Atterberg points out that there are similar close correlations between the nature of the pubescence of the rachilla and the lodicules.

The writer has observed that very often the nature of the pubescence of the edge of the rachis is similar to that found on the rachilla.

Form A.—Rachilla long-haired, the first pair of veins of the outer pale (which covers the corn) smooth (fig. 12).
Form B.—Rachilla long-haired, the first pair of veins of the pale having numerous teeth (fig. 13).
Form C.—Rachilla shaggy-haired, the first vein pair smooth.
Form D.—Rachilla shaggy-haired, the first pair of veins having numerous teeth.

AUXILIARY FORMS

Atterberg finally describes what he terms auxiliary forms thus:

Lax forms of *parallelum* and *erectum* are described as *laxum*.

Forms in which the long awns of the outer paleæ are not serrated and rough, but almost without teeth and smooth, are denoted by the name *læve*.

Forms with branching ears are named *ramosum*.

Forms with long awns are *longisetum*, and with short awns *brevisetum*; forms which lose their awns are *dejiciens*; forms with long ears are *longum*, and with short ears *breve*.

Variations in the colour of the corns are denoted by the names *cœrulescens*, *fuscum*, and *violaceum*.

Typical examples of Atterberg's sub-varieties grown in the United Kingdom are:

- *H. hexastichum*, commonly known as six-rowed barley, is cultivated as a winter sort but not to any great extent.
- *H. vulgare*, commonly known as four-rowed barley (but as shown previously in reality a lax six-rowed form), and in Scotland, where it is cultivated as both a spring and winter sort, as "bere" or "bigg".
- *H. zeocrithum*.—Fan, Peacock, and Spratt barley, the latter being extensively grown in the Fen district and more recently in Ireland.
- *H. erectum*.—Goldthorpe, Standwell, Brewers' Favourite, and Archer.
- *H. nutans* includes all forms of Chevallier barley—Hallett's, Scotch, Kinver, Old Irish.

VARIETIES OF IMPORTED BARLEYS

Large supplies of brewing and feeding barleys are imported into the United Kingdom annually, mainly from Argentine, California, Chili, Black Sea, the Danube, Ouchak, Persia, &c.

The varieties of which such importation consists are shown as follows:

- Argentine.—*H. vulgare*.
- Californian.—*H. distichum* and *H. vulgare*. Frequently a mixture of both varieties.
- Chilian.—*H. distichum* and *H. hexastichum*.
- Black Sea.—*H. vulgare*.
- Danube.—*H. vulgare*, with mixture of *H. distichum*.
- Ouchak.—*H. distichum*, with some admixture of *H. vulgare*.
- Persia.—*H. hexastichum*; *H. vulgare*, vars. *pallidum* and *nigrum*; and *H. distichum*, vars. *nutans* and *nigro-nutans*.

CULTIVATED BARLEYS

The varieties of malting barley most commonly cultivated in the United Kingdom include the following: Archer (sometimes called Archer's Stiff Straw or Archer's Chevallier), Goldthorpe, Plumage, Standwell, and Chevallier, which includes types such as Hallett's and Kinver Chevallier. To these, several varieties may be added which, on account of their special suitability to certain soils, are almost indigenous. Thus Spratt is mainly confined to the Fen districts of England, Old Irish to some of the late-ripening districts in Ireland, and Scotch Common to certain clearly defined, usually the later, districts in Scotland.

Of more recently introduced varieties, Plumage-Archer, Archer-Goldthorpe, and Spratt-Archer are the best known.

Characteristics of Cultivated Varieties

Archer.—This variety is frequently regarded as belonging to the Chevallier or *nutans* class of barley, but, apart from the fact that it approximates that type in shape of ear, being a lax form of *H. erectum*, it possesses none of the characteristics usually associated with varieties of the Chevallier class (see fig. 5).

The straw of Archer is short, stiff, and of a greyish colour. The "neck"—or that portion of the uppermost internode of the stem from the point where the leaf sheath ceases and the leaf blade begins, to the base of the ear—is short, and likewise erect. The ear is of the *erectum* type but lax, and does not show any evidence of nodding or bending on itself, to which characteristic barleys of the *nutans* type owe their name.

The grain is grey in colour, and in well-ripened samples the skin shows very fine wrinkling. The rachilla is short and covered with long hairs. The base of the corn has only a small basal surface.

On account of its heavy yielding qualities and special suitability to light classes of soil, Archer is extensively cultivated in the eastern counties of England and in Ireland. It is somewhat slow in ripening, and consequently less well suited to the north of England and to Scotland, where the shorter and cooler seasons and heavier nature of the soils necessitate the use of quicker ripening types.

Whilst Archer is specially well suited to light, gravelly soils with well-drained subsoils, it can be cultivated successfully on a wider range of soils than any of the other varieties at present under consideration.

Archer is a variety capable of standing rough handling, either in the shape of heavy wind and rain and storm during growth, or in harvesting, without incurring loss by heads breaking off the straw, the shortness of the neck and the wiriness of the straw rendering it wonderfully immune in this respect.

Further, the grains do not adhere as closely to the rachis as in the case of broad-eared types such as Goldthorpe, and it is consequently an easy barley to thresh.

Goldthorpe.—This barley originated from a single ear found in a field of Chevallier barley, near Goldthorpe, Notts, by Mr. William Dyson.[1] The straw of Goldthorpe is long and bulky and of a beautiful yellow colour. The neck is long, and somewhat brittle when ripe.

The ear is of the dense *erectum* type. The grain is yellow in colour, the rachilla short and covered with long hairs; the basal surface is large with a distinct nick (see figs. 4 and 9).

Of pure, as distinct from hybrid, forms, this is probably the best type of broad-eared variety in cultivation. Goldthorpe is not suited to so wide a range of soils as Archer, and appears, from the results of a large number of trials in different parts of the country, to produce the best crops on fairly heavy soils. On light soils, and especially in dry seasons, Goldthorpe suffers greatly from drought, with the result that it becomes stunted in growth and produces very thin and "steely" grain.

As it ripens about 7 to 10 days earlier than Archer, this barley is grown extensively in the north of England and in Scotland.

The straw of Goldthorpe is inclined to become brittle on ripening, and this, together with the length of the neck, frequently entails considerable loss by ears breaking off in harvesting.

The grains of Goldthorpe adhere to the rachis very tenaciously, with the result that, instead of the threshing-drum detaching them, it breaks the rachis into a number of sections, to each of which the grains still adhere. In this condition portions of dismembered rachis and adhering grains are often carried out of the threshing machine as "cavings".

Plumage.—This is a broad-eared barley resembling Goldthorpe in appearance.

It was introduced into England in 1902 by Mr. E. S. Beaven, of Warminster, who obtained it from a well-known plant breeder in Denmark, Mr. Carl Hansen, by whom it had been selected from a general type of barley known in Sweden as Plumage Korn.

The straw of Plumage is long with a long neck.

The grain, which is slightly longer in shape than Goldthorpe, is under most conditions a very deep yellow colour.

Plumage is best suited to fairly deep soils and to land in good condition.

It is about a week earlier in ripening than Archer, and has been found remarkably prolific on land in good condition in parts of the north of England and in Scotland.

Chevallier.—Chevallier is the type of malting barley most generally grown in the United Kingdom until recent years. Under Atterberg's

[1] Beaven, "Various conditions affecting the malting quality of Barley", *Journal of the Royal Agricultural Society of England*, June, 1900.

classification it is *H. nutans*, C., and stands in the same relation to the *distichum* division that *H. vulgare* does to that of *polystichum* (see fig. 6).

Beaven (in the *Journal of Royal Agricultural Society of England*, Vol. II, No. 42, 1900) gives an account of the origin of Chevallier's barley, and quotes a letter on the subject written by the originator, the Rev. John Chevallier, of Aspall Hall, Suffolk: "A labourer (named Andrews) living in a cottage of mine at Debenham in this county, as he passed through a field of barley plucked a few ears, and, on his arrival home, threw them for his fowls into his garden, and in due time a few of the grains arrived at maturity, and as the ears appeared remarkably fine I determined to try the experiment of cultivating them."

This is probably the first account we have of the starting-point of any of our present-day varieties. Several Chevalliers are now in cultivation, and generally under the name of the seedsmen by whom they are propagated—such are Hallett's Pedigree and Webb's Kinver Chevallier. How far these are descended from the original selection, it is difficult to determine. In general characteristics they are very similar, and for descriptive purpose may be regarded as identical.

The straw of Chevallier is long and somewhat weak; in colour it is a bright, lightish yellow. The neck is long, and, when the ear is ripe, bends like a well-sprung fishing-rod. The ear is generally long, lax, and bent on itself.

The grain is bright, lightish yellow in colour, and in normal samples well bellied. The rachilla is long and covered with short hairs; the base of the grain shows a very small basal surface.

On account of its good malting quality and bright attractive appearance, this barley was for many years extremely popular both with growers and buyers. It suffers, however, from the defect of a weak straw, and on rich soils and in seasons in which the conditions favour rapid growth it is extremely liable to "lodge". Recently owing to the extended introductions of the more productive and stiffer-strawed Archer, it has failed to maintain its once general popularity.

The writer has had occasion to notice a curious distinction between the straw of Chevallier and Archer after both had been blown down in a storm. The Chevallier straw broke over at one of the lower nodes, and the ears assumed a recumbent position from which they never recovered; the grain consequently filled very slowly and imperfectly, and harvesting was accomplished with a maximum amount of waste. The straw of the Archer immediately after the storm was flat on the ground for its whole length, but quickly "kneeded" up at the uppermost nodes. Raised off the ground in this way the grain continued to fill, and when threshed was found to be remarkably good.

Spratt.—Although not a variety commonly sown for malting, Spratt deserves consideration here for several interesting reasons. It is,

firstly, the only representative of *H. zeocrithum* (Atterb.) at present grown, and at the same time probably one of the oldest kinds in cultivation in the United Kingdom (see fig. 3). Spratt is further a good example of the adaptation of a variety to a particular class of soil. It is very stiff strawed, and grows prolific crops on soils rich in organic matter, the high yield obtained more than compensating for the somewhat unattractive appearance of the grain. It is grown extensively in the Fen districts of England, and more recently on peaty soils adjoining the celebrated bogs in Ireland.

The straw of Spratt is longer than Archer, but not so long as Goldthorpe or Chevallier, very stiff and erect. The ear is dense (denser than Goldthorpe), and borne on the straw in an erect manner. The grain is a dull grey in colour, and liable to be slightly irregular in size. There is a very distinctive hollow in the upper portion of the groove of the grain. The rachilla is short and covered with long hairs. The base of the grain has a large basal surface but no nick.

Only pure varieties have been dealt with up to the present, but there are in cultivation several hybrid varieties of considerable economic importance, amongst which Standwell, Plumage-Archer, Spratt-Archer, and Archer-Goldthorpe may be mentioned.

Standwell.—This is a broad-eared barley raised by Messrs. Garton of Warrington by crossing Chevallier and Fan barley (*H. nutans* and *H. zeocrithum*).

The straw is long and of a whitish yellow colour; neck long, and the whole straw very brittle when ripe.

The grain is large and whitish yellow in colour; the rachilla is short and covered with long hairs. The base of the corn shows a large basal area.

Plumage-Archer.—This is a broad-eared hybrid barley raised by Mr. E. S. Beaven by crossing Plumage with one of his pure lines of Archer, the object of the cross being to obtain a broad-eared form with a shorter neck, and thus to reduce the loss by necking so frequent in Goldthorpe and Plumage.

The straw of this barley is wonderfully short and erect, and the neck, like that of Archer, is short and not liable to necking.

The grain in many respects resembles Archer, but is stated to be of better colour and of distinctly superior malting quality.

Plumage-Archer is specially recommended for soils in high condition where good standing straw is essential.

Spratt-Archer.—This is a narrow-eared variety produced by the Plant Breeding Division of the Irish Department of Agriculture by crossing Archer and Spratt. The initial object of the cross was to obtain, if possible, a barley of the Archer type with the decidedly stiffer straw of Spratt.

The straw of the new hybrid barley is slightly longer than Archer, with a short neck, but is decidedly stronger.

The grain, whilst resembling that of the parent Archer very closely, is slightly brighter coloured.

Spratt-Archer is a few days earlier in ripening than Archer. According to the experiments carried out by the Irish Department in 1919 and 1920, Spratt-Archer is superior to the parent Archer in point of yield, while in quality there is little to choose between the two varieties.

Archer-Goldthorpe.—This barley, also raised by the Irish Department, is a broad-eared variety obtained by crossing Archer and Goldthorpe, the object of this cross being to obtain a broad-eared variety with a short neck, and consequently immune to loss by ears breaking off the straw when ripe.

The straw and neck of Archer-Goldthorpe are very short, in these features resembling the parent Archer.

In shape the grain is long, with a decided nick at the base, and is finely wrinkled when ripe, in this respect being very similar to Archer.

The grain is of good quality, and as the barley is of distinctly early ripening habit it is likely to prove a valuable type for the heavier classes of soil in good condition.

AREA UNDER CULTIVATION

The area of land under barley in the United Kingdom has shown a steady decline from 2,930,000 acres in 1879 to 1,880,000 in 1914.

A more rapid fall occurred in 1915—from 1,880,000 to 1,520,000—but this was gradually rectified from that year until 1920, when the official return was over 2,000,000, the highest acreage since 1902.

The distribution in the four countries is shown in the following table. In order to obtain an idea of the relative importance of barley and the two other chief cereals, the areas under wheat and oats are also included.

	Barley, 1914.	Wheat, 1914.	Oats, 1914.
England	1,420,346	1,770,470	1,720,082
Wales	84,425	37,028	199,535
Scotland	194,109	60,521	919,580
Ireland	172,289	36,913	1,028,758
United Kingdom ..	1,871,169	1,904,932	3,867,955

Of the total acreage roughly 76 per cent is found in England, and about

20 per cent in Scotland and Ireland. It will be seen that the total acreage of wheat and barley in the United Kingdom taken together closely approximates that under oats.

Fig. 14.—Area under Barley for each Decennial Period, 1870–1920

The geographical distribution of the barley acreage is of interest, and gives a clear idea of the classes of soil and climatic conditions under which this crop is most successfully cultivated. For instance, taking the

area in England—1,420,000 acres approximately—half of this is found in the extreme eastern counties, thus:

Yorks	196,490 acres.
Lincolnshire	201,170 ,,
Norfolk	188,113 ,,
Suffolk	119,788 ,,
Essex	61,681 ,,
Kent	28,925 ,,
	796,167 ,,

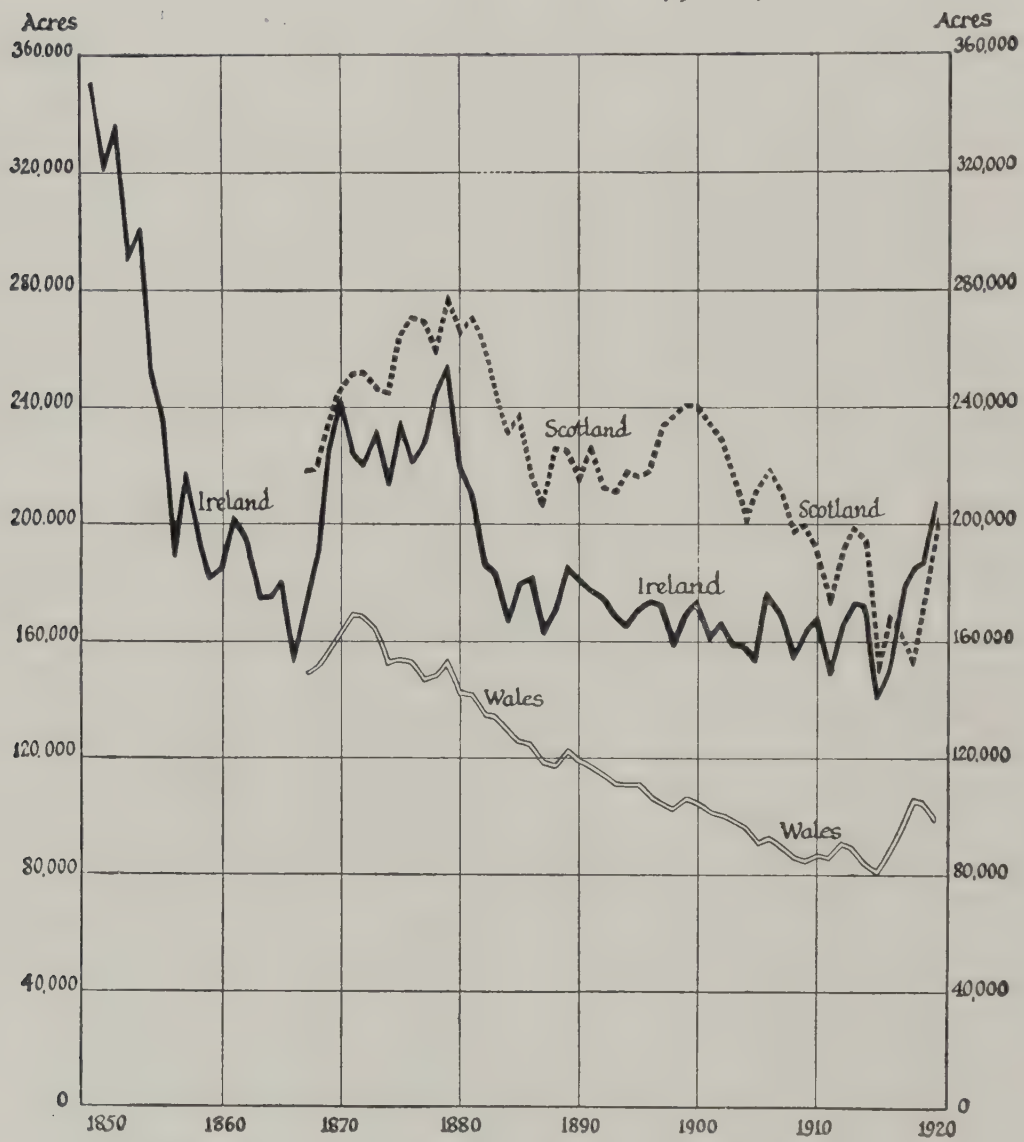


Fig. 15.—Area under Barley for each Decennial Period, 1850–1920

Of the balance the largest acreages are met with in the southern and south-eastern counties, but practically none in the north-western counties.

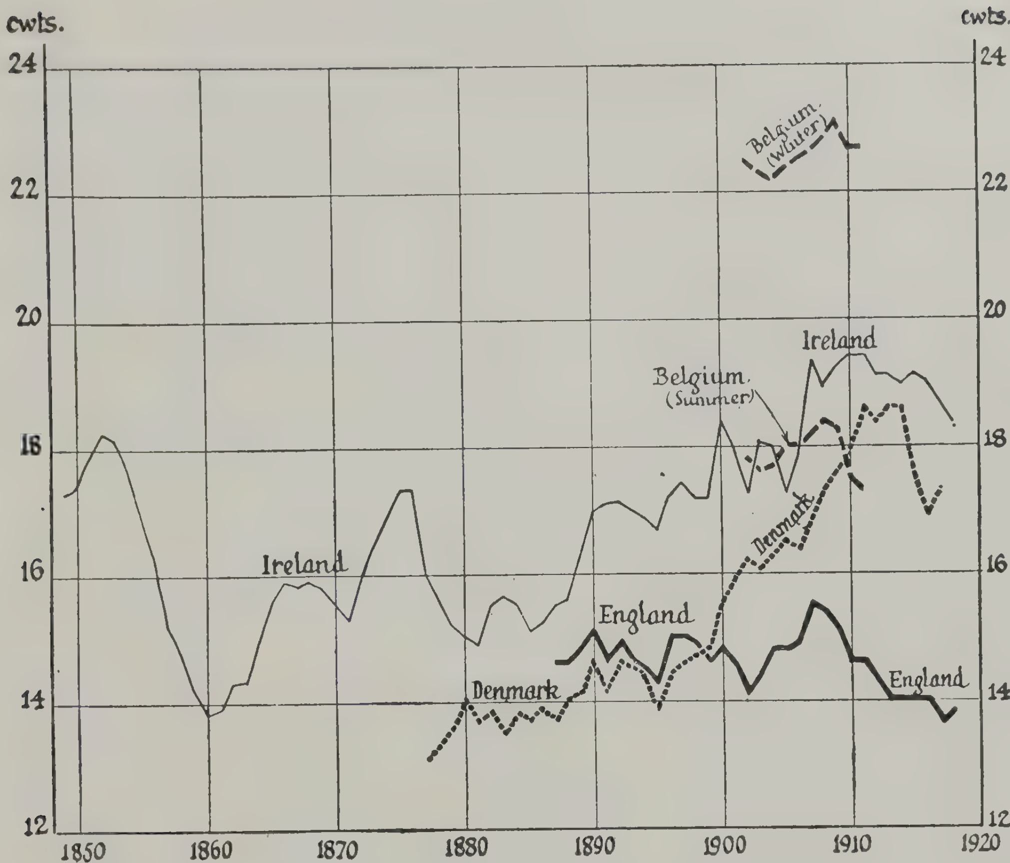


Fig. 16.—Average Yields per Statute Acre for each Decennial Period, 1850–1920

In Scotland the tendency again is to follow the eastern and south-eastern and central districts, as shown in the following table:

North and North-western.

Shetland, Orkney, Caithness, Sutherland, Ross and Cromarty, Inverness. } 22,698 acres or 11·15 per cent.

North-eastern.

Nairn, Elgin, Banff, Aberdeen, Kincardine. } 56,160 acres or 28·33 per cent.

East-central.

Forfar, Perth, Clackmannan, Kinross, Fife. } 56,636 acres or 28·57 per cent.

South-eastern.

Linlithgow, Midlothian, Haddington, Berwick, Roxburgh, Selkirk, Peebles. } 56,829 acres or 28·66 per cent.

Western and South-western.

Argyll, Bute, Dumbarton, Stirling, Lanark, Renfrew, Ayr, Dumfries, Kirkcudbright, Wigtown.	5925 acres or 2·99 per cent.

In Ireland very little barley is grown in the northern province of Ulster or the western province of Connaught, but is localized in the eastern and central province of Leinster and the southern province of Munster, as shown in the following table:

Leinster	121,563 acres.
Munster	41,469 ,,
Ulster	4,736 ,,
Connaught	4,518 ,,
	172,286 ,,

The eastern, south-eastern, and central counties here again show the largest acreages. Thus:

Louth	12,646 acres	(Eastern).
Wexford	34,848 ,,	(South-eastern).
Cork	16,878 ,,	,,
Queen's County ..	22,832 ,,	(Central).
King's County ..	16,600 ,,	,,
Kilkenny	16,510 ,,	,,
Kildare	12,175 ,,	,,
	132,489 ,,	or 76 per cent of the total.

SOILS AND CLIMATE FAVOURABLE TO BARLEY

It has been found, by long cultivation of this crop, that the most suitable soils for barley are those possessing a fairly high percentage of sand, rich in active carbonates, even in texture, and with free drainage, that is, readily worked open soils. While good crops of high-quality barleys are produced on soils of this character, prolific crops can also be grown on soils of a heavier nature, but on these there is a strong tendency to excessive vegetative development attended by too prolonged ripening and consequently very limited "maturation", the result being large, heavy grain of a "steely" character. On the other hand, on very light soils vegetative development is limited, and in hot summers there is a strong tendency to too rapid ripening, when the resulting grain is again steely in character. Any conditions of soil or climate which tend to unduly check or to unduly prolong the development of the barley plant are detrimental. Consequently it is found that medium loams in a fair state of

fertility and with good natural drainage produce the most remunerative crops, when judged over a period of years. Such soils are capable of withstanding the effect of anything except very severe droughts, and do not prolong the growth and ripening of the plant unduly.

The bearing of the climate is most clearly seen in its extreme effects. Thus in hot districts premature ripening is common, whilst in districts with a heavy rainfall immature grain is the rule.

Although the quality of barley may be influenced by such factors as soil, climate, variety, seed, and manures, climate undoubtedly exerts the most important influence. The following figures, which are the average total nitrogen figures (on dry matter) for samples of Archer and Goldthorpe drawn from the Irish experimental plots in the years 1901–9 inclusive, illustrate the bearing of this factor on the quality of the grain.

	Archer, per cent Nitrogen.	Goldthorpe, per cent Nitrogen.	Difference, per cent.
1901	1·51	1·59	0·08
1902	1·48	1·50	0·02
1903	1·65	1·63	0·02
1904	1·56	1·50	0·06
1905	1·55	1·56	0·01
1906	1·52	1·49	0·03
1907	—	—	—
1908	1·52	1·49	0·03
1909	1·47	1·46	0·01
Average	1·53	1·52	0·03
Year of highest nitrogen content, 1903 ..	1·65	1·63	
Year of lowest nitrogen content, 1909 ..	1·47	1·46	
	0·18	0·17	

The difference in nitrogen content for each year is given in the third column, and the average difference between the two varieties for the eight years is ·03 per cent.

The year of highest nitrogen content for both varieties was 1903, and the lowest, again for both, was 1909.

The difference between these two years is ·18 per cent for Archer and 0·17 per cent for Goldthorpe, or approximately *six* times the average varietal difference.

COMMERCIAL VALUATION OF BARLEY

The determination of the commercial value of different varieties of barley for malting has been the subject of research in different parts of the country for many years past. Regarding the matter in its widest bearing, the value of the crop to the producer is a product of the quantity of grain raised and the value per measure (whatever the standard may be). The producer must debit this amount with the cost of production, which figure is approximately identical for all varieties. Experience has shown, however, that stiff-strawed varieties of all cereals are more economical to handle and involve less risk than any others, and it is to such forms that the farmers' preference will instinctively lean, despite any advantage other varieties may offer in yield or quality, or both. This applies particularly to those countries or districts with a changeable climate and heavy rainfall. In harvest, when labour is scarce and the weather often adverse, the extra time involved in saving a heavy but lodged crop of one variety of corn may involve the loss of other crops. Consequently the determination of the value of any variety must be the result of the experience of many seasons.

The value of a sample of malting barley to a maltster who carries out the first step in the process of the manufacture of beer or spirits is determined: (1) by the condition[1] of the grain and the absence of anything in the nature of dead or damaged corn; (2) by the evenness in size of grain, freedom from small corn and weed seeds; and (3) by the degree of maturation and mealiness of the grain. In a well-ripened sample of barley the grain is well filled, the skin is finely wrinkled, and the interior presents a loose white mealy surface when cut across. Badly ripened grain, or grain that has been grown with an excessive quantity of nitrogen, is characterized by the absence of wrinkling, and the fracture on cutting is sharp and of a dull steely colour.

The operation of malting consists in treating barley in such a manner as will induce it to undergo the initial stages of germination. During this change the matrix, in which the starch granules are embedded, is disintegrated and the walls of the containing cells are partially or wholly dissolved. The starch granules are in this way made more easily accessible to the action of enzymes, which convert them into a soluble form in which they can be utilized by the young growing plant.

The grain is first steeped in water in large tanks for about twelve hours. It is then spread out on a floor to a depth varying with the temperature, but averaging about one foot. Once the grain shows signs of growing, usually by the fourth day, it is spread out in a thinner layer.

[1] "Condition" is a technical term used to indicate the degree of dryness of grain. Well-conditioned samples are those free from an excess of moisture.

The rootlets then make rapid development, and in about ten days the plumule has elongated under the palea until its tip reaches to a point about two-thirds up the back of the grain. During this time the interior of the grain, or endosperm, has undergone considerable change, and, instead of the hard surface it originally presented, has assumed a more or less loose and granular condition. At this point further growth is arrested by drying the grain on a kiln at such a temperature as will kill the young germ and at the same time reduce the moisture content to about 2 per cent.

The first stage in the germination of a seed is the liberation of ferments or enzymes, which act on the matrix, in which the starch granules are embedded, and on the containing cell walls. This change prepares the way for a more active attack of enzymes on the starch, rendering it soluble, and in this form capable of absorption by the germ.

During the period that these changes are in operation active respiration is proceeding, oxygen is absorbed, and carbon dioxide evolved—the latter at the expense of the carbonaceous matter of the endosperm. Consequently the shorter the period required for the effective liberation of the starch granules from the matrix and their conversion into forms suitable for the nutrition of the germ, the smaller will be the loss of valuable carbonaceous matter entailed.

It has been found that "steely" barleys are difficult to malt, and occupy a longer time in modifying on the malt floors than "mealy" barleys. The quantity of extract they produce is also less than that obtained from the same quantity of "mealy" grain, and contains an additional quantity of albuminoid material which may, and often does, exert a detrimental effect on the keeping qualities of the resulting malt liquor.

It is not difficult to differentiate between distinctly mealy and steely barleys by the eye, but when dealing with smaller differences an exact discrimination is not possible by this means. Attempts have consequently been made to correlate the chemical composition and malting value of different classes of barley.

Beaven,[1] in 1902, published the results of a large number of chemical analyses of barley grown under varying circumstances, and definitely established the fact that when grown under like conditions steely barleys are characterized by a high, and mealy barleys by a low, total nitrogen content.

Very high quality barley may have a nitrogen content as low as 1·1 per cent and low qualities as high as 2 per cent, or about 7 per cent and 13 per cent albuminoids, on dry matter. The average nitrogen content of malting barley is approximately 1·5 per cent.

Beaven states very clearly, however, that nitrogen content alone is only useful as an index of quality for comparing barleys which are in other

[1] *Journal of the Federated Institute of Brewing*, Vol. VIII, No. 5, 1902.

respects approximately alike. Thus a thin, indifferently filled grain may have a low nitrogen content due to the high proportion of husk, which has been shown to contain only half as much nitrogen as the same weight of endosperm, while a well-filled grain may, on account of the relatively greater quantity of endosperm, show a relatively higher nitrogen content.

These conclusions have been confirmed by many other investigators, and the total nitrogen content is now very generally used in practice as a reliable criterion when valuing home-grown barleys.

POSITION OF BARLEY IN THE ORDINARY FARM ROTATION

Barley usually occupies one of two positions in the rotation—it is sown either after a root crop, or after another corn crop.

Unlike oats and wheat, barley is only able to compete successfully with weeds to a very limited extent; consequently it is an advantage to sow it after a cleaning crop whenever possible.

Root land on which sheep have been folded, however, is often too rich for barley, with the result that the crop " lodges ", and the grain is nitrogenous in character. On this account it is the custom in some districts to sow wheat or oats immediately after the root crop, and then follow with a crop of barley. The wheat or oat crop reduces the richness of the land, and the succeeding barley crop, although probably smaller in yield than when taken directly after the roots, will stand better and produce grain of higher malting value.

Barley is sometimes sown after a seeds ley, but this is neither a common practice nor is it one to be generally recommended, as the soil is liable to be too rich and the growth of the barley very uneven.

If it is necessary to sow barley after ley, considerable benefit may be derived from the application of 3 cwt. per acre of a mixture of superphosphate and kainit, which will check the excessive growth of straw, and improve the quality of the resulting grain.

MANURING OF BARLEY

When barley is sown after a root or manured crop, the question of manuring does not arise, as the land is then sufficiently rich to supply the food requirements of the crop.

When sown after another corn crop, however, and especially on land that is not in high condition, it is necessary to assist the crop with some form of manure. Ordinary farmyard manure may be used for this purpose, but in farming practice the quantity directly available for corn crops is limited; and further, it is generally considered that barley suc-

ceeds better when supplied with the necessary plant food in a readily available form than when manured with bulky manures, such as farmyard manure, which undergoes nitrification over an extended period.

The effect of the application of artificial manures, such as ammonium sulphate and nitrate of soda, alone is to stimulate the crop, whereby a large increase in the yield of both grain and straw is obtained. On most soils the increased return of grain and straw from these two manures is very similar. Cases have been recorded[1], however, where on Wold soils nitrate of soda, in combination with mineral manures, is more effective than sulphate of ammonia in a similar mixture. In one or two cases the seasons in which these trials were made were very dry, when nitrate of soda would absorb atmospheric moisture and so benefit the plant in a secondary manner. The relative differences in the effect of the two manures may thus be due to seasonal conditions only.

To a limited extent sulphate of ammonia may be directly assimilated by the plant, but in the main it must undergo nitrification before exerting its maximum effect on the growing plant. If the length of time occupied in nitrification is prolonged, assimilation likewise extends over a considerable period. Under these circumstances there is a tendency for the plant to remain green and for ripening to be unduly delayed, on which account the use of more quickly acting nitrate of soda is preferred.

Up to a certain point nitrogenous manures when applied to barley are distinctly beneficial, but a point is soon reached beyond which, if they are used, it is at the risk of the over-production of soft, succulent, late-ripening straw, and of thin, coarse, and very nitrogenous grain—material in all respects undesirable for malting.

Phosphatic and potassic manures when used alone usually result in a small increased return of grain and straw, but the relative effects are determined by the phosphoric acid and potash requirements of the soil to which they are applied.

Both forms of manure, when used either alone or in combination, influence the filling of the grain beneficially, whilst the straw from the crops so treated is much shorter and more rigid than when nitrogenous manures alone are applied. It is only in combination with nitrogenous manures, however, that the full benefit of phosphatic and potassic applications is obtained, the yield of both grain and straw when a complete mixture—i.e. one containing the three essential plant foods, nitrogen, phosphoric acid, and potash—is used being appreciably greater than when any one form of manure alone is applied.

Nitrogenous manures thus appear to stimulate the formation of the framework of the plant, while the mineral manures are mainly concerned in the changes which ultimately result in the filling of the grain.

[1] Pamphlet No. 37, University of Leeds and Yorkshire Council for Agricultural Education.

One striking effect of phosphatic manures on corn crops is the manner in which they accelerate ripening, often by periods of from seven to ten days. It has frequently been recorded that experimental plots dressed with a mixture of nitrogenous and phosphatic manure are invariably ready to cut before the plot to which nitrogenous manure only has been applied.

In practice advantage is taken of this fact by applying some form of phosphatic dressing to fields on which corn crops are known to ripen late, thereby hastening ripening, and at the same time producing better filled grain.

Phosphatic manures may be used with advantage on barley grown on well manured root land fed off with sheep. In such cases this manure will prevent over luxuriant growth, hasten ripening, and reduce the tendency to the production of nitrogenous grain.

The most remunerative mixture of artificial manures for the generality of barley soils is: 1 cwt. sulphate of ammonia or its equivalent of nitrate of soda, 3 cwt. superphosphate, 2 to 3 cwt. kainit per acre.

The relative quantities of the various manures forming the mixture may be varied to suit the ascertained quality of the land to which it is applied, but there are few conditions that warrant the use of more than 1½ cwt. per acre of nitrogenous manures.

The best time to apply such a mixture as the above is a day or two before sowing, when advantage can be taken of the cultivation necessary in the preparation of the seed bed to get the manure thoroughly mixed in the soil.

If for any reason the crop requires stimulation during the early stages of growth, about ½ cwt. of nitrate of soda or sulphate of ammonia may be applied broadcast, but for reasons already mentioned care must be exercised to avoid the application of such a quantity of these fertilizers as will over-stimulate the plant, with the resultant ill effects of excessive straw production, late ripening, and then nitrogenous grain.

While the general effect of the use of artificial manures, either alone or in combination, is as stated above, it must always be borne in mind that the special manurial requirements and fertility of the particular soil under review are factors which determine the monetary return from each application.

As illustrating the bearing of these points, the results of a series of manurial experiments, carried out by the Department of Agriculture, Ireland, at three centres, in 1907, are given below in detail.

Barley Manuring Experiments, 1907. Department of Agriculture, Ireland

Farm 1.—Crops: 1905, Roots; 1906, Oats.
Soil: Good Drift Loam.
Subsoil: Gravel and Yellow Clay.
Geological Formation: Carboniferous Limestone.

Description of Experiment.	Farm No. I, Carlingford, Co. Louth.																	
	Yield per Statute Acre.		@		Value.			Screenings.	Total Value with Screenings.			Bushel Weight.	Cost of Manure per Acre.		Profit or Loss.		
Plot No.	Qr.	St.	s.	d.	£	s.	d.	Per Cent.	£	s.	d.	Pounds.	s.	d.		s.	d
(1) Unmanured	5	20	30	0	8	8	9	2·0	8	11	3	54	—			—	
(2) 1 cwt. ammonium sulphate	6	28	29	6	10	2	10	3·5	10	7	10	53¾	14	6	+	21	1
(3) 3 cwt. superphosphate	5	28	30	0	8	16	3	2·0	8	18	9	53¾	10	6	—	3	0
(4) 3 cwt. kainit	4	28	30	0	7	6	3	2·5	7	8	9	54¼	8	0	—	20	6
(5) 1 cwt. ammonium sulphate and 3 cwt. superphosphate	5	24	30	0	8	12	6	2·1	8	15	0	53¾	25	0	—	21	3
(6) 1 cwt. ammonium sulphate and 3 cwt. kainit	5	24	30	0	8	12	6	1·8	8	14	8	54	22	6	—	19	1
(7) 3 cwt. superphosphate and 3 cwt. kainit	5	16	30	0	8	5	0	1·9	8	7	2	54	18	6	—	22	7
(8) 1 cwt. ammonium sulphate, 3 cwt. superphosphate, 3 cwt. kainit	5	22	30	0	8	10	7	1·5	8	12	4	54¾	33	0	—	21	11

BARLEY MANURING EXPERIMENTS, 1907. DEPARTMENT OF AGRICULTURE, IRELAND (*Continued*)

Farm 2.—Crops: 1905, Roots; 1906, Barley.
Soils: Good Strong Loam.
Subsoil: Yellow Clay.
Geological Formation: Carboniferous Limestone.

Description of Experiment.	Farm No. 2, Midleton, Co. Cork							
	Yield per Statute Acre.	@	Value.	Screenings.	Total Value with Screenings.	Bushel Weight.	Cost of Manure per Acre.	Profit or Loss.
Plot No.	Qr. St.	s. d.	£ s. d.	Per Cent.	£ s. d.	Pounds.	s. d.	s. d.
(1) Unmanured	3 12	29 0	4 17 10	30·7	6 7 10	51	—	—
(2) 1 cwt. ammonium sulphate	3 0	29 0	4 7 0	37·1	6 4 6	51	14 6	− 17 10
(3) 3 cwt. superphosphate	4 18	29 0	6 12 4	18·8	7 13 7	51½	10 6	+ 15 3
(4) 3 cwt. kainit	4 20	29 0	6 14 1	17·7	7 14 1	52	8 0	+ 18 3
(5) 1 cwt. ammonium sulphate and 3 cwt. superphosphate	4 12	29 0	6 6 10	26·3	7 18 1	51½	25 0	+ 5 3
(6) 1 cwt. ammonium sulphate and 3 cwt. kainit	4 26	29 0	6 19 7	21·4	8 5 10	51½	22 6	+ 5 6
(7) 3 cwt. superphosphate and 3 cwt. kainit	4 28	29 0	7 1 4	13·3	7 16 4	52	18 6	+ 10 0
(8) 1 cwt. ammonium sulphate, 3 cwt. superphosphate, 3 cwt. kainit	4 30	29 0	7 3 2	18·5	8 5 8	52	33 0	+ 4 10

BARLEY MANURING EXPERIMENTS, 1907. DEPARTMENT OF AGRICULTURE, IRELAND (*Continued*)

Farm 3.—Crops: 1905, Roots; 1906, Barley.
Soil: Sandy Loam.
Subsoil: Sand and Limestone Gravel.
Geological Formation: Carboniferous Limestone.

Description of Experiment.	Farm No. 3, Monasterevan, Queens Co.							
	Yield per Statute Acre.	@	Value.	Screenings.	Total Value with Screenings.	Bushel Weight.	Cost of Manure per Acre.	Profit or Loss
Plot No.	Qr. St.	s. d.	£ s. d.	Per Cent	£ s. d.	Pounds.	s. d.	s. d.
(1) Unmanured	4 6	29 0	6 1 5	7·5	6 8 3	51¼	—	—
(2) 1 cwt. ammonium sulphate	4 20	29 0	6 14 1	6·9	7 0 11	51½	14 6	— 1 10
(3) 3 cwt. superphosphate	3 20	29 6	5 6 11	6·4	5 11 11	52¼	10 6	— 26 10
(4) 3 cwt. kainit	4 8	29 6	6 5 4	5·8	6 10 8	52	8 0	— 5 7
(5) 1 cwt. ammonium sulphate and 3 cwt. superphosphate	4 4	29 6	6 1 8	7·0	6 7 11	52	25 0	— 25 4
(6) 1 cwt. ammonium sulphate and 3 cwt. kainit	4 18	29 6	6 14 7	7·0	7 1 5	52¾	22 6	— 9 4
(7) 3 cwt. superphosphate and 3 cwt. kainit	3 20	29 6	5 6 11	6·8	5 12 3	52¼	18 6	— 34 6
(8) 1 cwt. ammonium sulphate, 3 cwt. superphosphate, 3 cwt. kainit	4 18	29 6	6 14 7	9·6	7 4 4	52	33 0	— 16 11

Centre 1 was situated in the northern portion of the barley-growing areas, Centre 2 in the southern, and Centre 3 in the midland area. The yields of the "unmanured" plot, No. 1, indicate at once the relative fertility of the three soils on which the trials were conducted, and it is apparent therefrom that the largest relative return may be expected from manures used at Centre 2.

The soil at Centre 1 is in a high state of fertility, and the application of superphosphate and kainit, both alone or in combination, although it results in a slight increase of yield in the case of the former, is accountable for a considerable reduction in the case of kainit, and on the whole three plots ends with a monetary loss. It is thus evident that the soil is plentifully supplied with mineral manures, a conclusion which is borne out by the result obtained from the plot receiving 1 cwt. sulphate of ammonia. Here a large increase of grain of good quality is obtained, indicating that the nitrogenous dressing has been able to take advantage of the available phosphates and potash already in existence in sufficient quantities in the soil.

At Centre 2 the soil is apparently more deficient in phosphates and potash than in nitrogen, and here kainit is the most profitable manure.

At Centre 3 the results indicate a deficiency of nitrogen and potash, and larger applications of these two manures would probably have proved more remunerative. A considerable monetary loss occurs where superphosphate only was applied.

The percentage of screenings is a good index of the extent to which manures influence the filling of the grain, and in these cases the mineral manures have apparently exerted a beneficial effect.

PREPARATION OF SEED BED

Unlike wheat, and, to a lesser extent, oats, barley is a shallow-rooted cereal drawing all its food supply from the upper three or four inches of the soil. As the root range is a limited one, the object of the grower should be to prepare the land in such a manner as will ensure easy and rapid penetration of the soil by the fine fibrous root hairs of the plant.

Land that is intended to be sown with spring barley should be ploughed early in the autumn, thus allowing it to benefit by the action of frost. By early spring it will have broken down into a fine condition, and all that will then be required to prepare it for seeding is a light cultivation and harrowing.

On light readily worked soils the latter operation alone will be sufficient, but where for any reason the land is lumpy it should be harrowed, and if necessary rolled until perfectly fine.

If the land is not ploughed until early spring, it may then be necessary to cultivate it previous to harrowing down prior to drilling.

TIME OF SOWING

For the production of both quantity and quality, the evidence of experience and experiment is that the earlier barley is sown the better, always provided the soil is in a fit condition to receive the seed. Nothing is to be gained by commencing to sow before the land is dry, and sufficient fine soil is available to cover the seed well.

Some interesting results from the Danish experiments on the value of barley when sown early and late may be quoted here:

Date of Sowing.	Yield.	Weight of 1000 Corns: Grammes.	Points of Valuation.[1]			
			Form.	Colour.	Quality.	Total.
	Cwt.					
April 3 ..	20⅛	45·0	4·6	3·9	4·0	12·5
„ 11 ..	21⅛	43·4	4·3	3·8	3·9	12·0
„ 20 ..	20⅛	43·1	4·2	3·7	3·8	11·7
„ 28 ..	19⅝	43·4	4·0	3·6	3·7	11·3
May 6 ..	18⅝	43·2	3·0	3·4	3·3	10·3

It will be noted that sowing in Denmark does not commence until about 10th April. In the earlier districts in the United Kingdom sowing in favourable seasons may commence from about the middle to the end of February, and is fairly general about the middle of March.

In Canada sowing does not begin until early May, the period of growth being about 100 days compared with 150 in these islands, but in that country, as in America, barleys are generally thin and steely, a condition which is undoubtedly to be attributed to the short period of growth. Even in this country it has been repeatedly noted that with a hot summer, and consequently rapid ripening, barley is very inclined to be thin and steely, more particularly on light soils.

Early sowing combined with gradual and uninterrupted growth and development appear to be the conditions most favourable to the production of heavy yields and high quality in malting barley.

RATE OF SOWING

It has been found that the quantity of seed required may vary considerably, but always bears a relation to (*a*) the time of sowing, (*b*) the

[1] This method of valuation is used very much in connection with these plots. The marks are awarded under each of the three headings, the maximum being eight, the total marks giving a fair comparison of the different barleys.

nature and fertility of soil on which it is sown, and (*c*) the method of sowing, that is, whether a seed drill is used or the seed is sown broadcast. The average quantity sown is between $2\frac{1}{2}$ and 3 bus. per acre. When early sowing is practised, the larger quantity should be used as a provision against losses arising from adverse climatic conditions and the depredation of birds.

The condition to be aimed at in deciding upon the quantity of seed to be used is a maximum number of heads of barley per acre, always provided, on the one hand, that the vegetative development is not excessive, thereby rendering the crop liable to lodge, and, on the other hand, that the competition between plants is not so great as to arrest vegetative development. In circumstances such as the latter, plants are rendered diminutive in size, an example of which is frequently to be seen on the headlands of fields where the land is double seeded, or where for other reasons too great a quantity of seed is sown on a given area. Soils in a high state of fertility require less seed than poorer soils, but the quantity should not be so far reduced as to cause excessive tillering, and, as a result, unequal ripening. Again, on thin sandy soils a full quantity of seed may be used, but care should be exercised here to avoid overseeding for the reasons mentioned previously.

When sowing broadcast more seed will be required than when a seed-drill is used. It is possible that under special circumstances smaller quantities of seed than the above may prove to be sufficient, but on the generality of barley soils an extreme departure from these figures will only be at the expense of the yield or quality of the resulting grain.

The average depth at which barley is sown is 2 to 3 in. When sown at a less depth the plant is not held firmly in the soil, and consequently there is a greater liability of the crop lodging. If sown deeper than 2 to 3 in. many of the plants fail to reach the surface of the soil.

The writer carried out a small experiment in 1905 with the object of ascertaining the number of plants surviving when the seed was sown at different depths. The variety used for the purpose was Archer, and the grains, twelve of which were sown at each depth, were as nearly as possible all of the same size.

The depths at which the seeds were sown and the number of plants surviving at each depth were as follows:

Depth	1 in.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.
Plants surviving ..	11	11	9	11	9	5

The experiment indicates that while 3 in. is not an excessive depth, the limit is being rapidly reached at about $3\frac{1}{2}$ in.

The plants sown at the shallow depths produced a greater number of tillers per plant than those more deeply sown, but the plants were so loosely

held in the soil that they required artificial assistance to maintain them in an upright position.

METHOD OF SOWING

Barley, like other cereals, was up to recent years generally sown broadcast by hand, but this practice is rapidly giving way to sowing with the seed-drill, of which there are many makes on the market. The advantage of the drill lies chiefly in the fact that the grain is deposited in the soil at regular intervals and at the same depth, thus ensuring uniformity of growth in the early stages of the plant's development. Again, in a well-prepared seed bed the grain is deposited by the drill in such a manner as to ensure adequate cover. As the number of surviving plants is greater when the seed is drilled, the quantity of seed required per acre is less than when sown broadcast. Drilled corn can be more effectively cleaned by the harrow than broadcast corn, and where grass seeds are sown with the crop they have a better chance of establishing and maintaining themselves. The distance between the rows of drilled corn varies from 4½ to 7 in., the former being the practice on light and the latter on soils it is intended to hand weed. The average width of drill is 5½ to 6½ in.

SUBSEQUENT CULTIVATION OF THE CROP

This is limited to weeding, harrowing, and rolling when the plants have commenced tillering. If weeds such as the ordinary creeping thistle are present, the most satisfactory plan is to pull them by hand, but small annual weeds can be effectively countered by harrowing.

Rolling after harrowing assists in making the soil firm round the young growing plants, thereby promoting tillering and checking the attacks of leather jacket and wireworm.

Usually the crop is harrowed once and rolled once, but if the surface of the soil is badly caked two or more harrowings may be necessary. In the event of bad attacks by leather jacket or wireworm it may be necessary to roll several times, but under normal conditions one rolling is sufficient.

When grass seeds are sown with barley the crop is lightly harrowed when two or three inches high, and the " seeds " then sown either broadcast or with a seed harrow, and finally rolled.

In the last few years spraying with a solution of copper sulphate to kill charlock has become a regular feature of the routine of barley cultivation. The practice is remarkably successful in destroying the charlock, but is very liable to check the growth of the corn for a few days. If all spraying is followed by rain the barley recovers quickly from any ill effects,

but in any case the destruction of an extremely harmful and troublesome weed more than compensates for the reduction in yield that may result from this practice.

SEED

The first essential of any seed is that it shall germinate, and be in a condition to produce a strong healthy plant. The germinating capacity of barley seed is governed to a large extent by the conditions under which it was harvested, and afterwards by the manner in which it was stored through the winter months. If the grain is in low condition when harvested, i.e. if it contained too much moisture, excessive heating may take place in the stack, and the vitality of the germ be thus seriously impaired, and, in extreme cases, killed. When harvested under good conditions, however, the grain will benefit by undergoing a certain amount of natural drying in the stack.

In Ireland, where the condition of grain crops when harvested is often low, and the heavy winter rainfall excludes any chance of natural drying, a system of artificial drying is in common use. The grain, as it is threshed in the autumn, quickly changes hands to the local maltster, and on arrival at the maltings is immediately placed on a drying kiln to a depth of about 6 in. The temperature of the kiln at loading is about 80° F., and this is very gradually increased so that it rises to 110° F. in four to five hours. In this period the grain will have lost approximately 5 per cent of moisture. The moisture in the grain in an average season is from 17 to 18 per cent, and in very wet seasons much higher; and it must be dried down to 12 per cent before it can be stored in bins or silos without risk of injury by subsequent heating. It has been found that the vitality of barley will not be injured by considerably higher temperatures than those indicated, provided drying is commenced at a low point and the temperature raised very gradually, free evaporation of the escaping moisture always being promoted at the same time by turning the grain frequently.

The immediate effect of artificial drying is to depress the germinating capacity slightly, but if care has been exercised in the process this rapidly rectifies itself.

The advantages of drying seed artificially are considerable, but chiefly that grain so treated may be stored away in large bulks in bins or silos, &c., and the necessity for repeated turning during the winter obviated.

Further, once the moisture content is brought down to 12 per cent, barley will not reimbibe much beyond this figure, the germinating capacity of the grain is maintained, frequently for several seasons, and finally the seed when sown germinates quickly, vigorously, and *evenly*.

While it is necessary to know the germinating capacity of any bulk

of seed, a factor that must not be lost sight of is vigour. Seed that is not properly stored may still germinate, but its vigour is frequently impaired to such an extent that, even under the best conditions, it can only produce a decidedly inferior crop.

Size of Seed.

Barley intended for seed should be even in size, free from injured grain and weed seeds.

The results of numerous experiments indicate that the large grains coming from the middle of the ear produce more vigorous plants, and consequently heavier crops than the smaller grains from the top and bottom of the ear. Other things being equal, it is advisable therefore to sow the largest grain possible, always provided the seed is within a pure line. The indiscriminate use of seed selected entirely by reason of its size and without any regard to its variety or pedigree is devoid of any scientific reason.

A further factor, and one which may ultimately be proved to be of considerable importance, is the geographical origin of the seed.

Experiments have shown that, quite apart from physical conditions influencing the germinating capacity of grain, the productivity of pure line cultures shows a considerable variation according to the soil on which they are grown. It is evident, of course, that the causes of such variation, whatever they may be, are a combination of many factors but certainly of the two—soil and climatic environment. Present knowledge on this subject is not yet sufficiently advanced to permit of discrimination between soils producing seed of high and of low productivity, but the existing evidence points to the high productive value of seed taken from those soils and district where the particular variety under observation is most productive.

Thus the practice of using Scotch oat seed in England and in parts of Ireland, and of Irish and Scotch potato "seed" in England, may be quoted as verification of this statement.

As the yield of barley in Ireland is on the average higher than in Great Britain, it is probable that pure line seed drawn from the highest yielding districts in the former country will prove more prolific in Great Britain than pure line seed drawn from the generality of barley soils there.

Seed Selection.

Of the many aspects of agricultural development none is receiving more attention at the present time than seed selection. The subject is not entirely of recent introduction, for the widespread interest taken in genetics and the problems attendant on this subject in recent years have assisted in focusing agricultural interest on a problem of immense importance to all concerned in the cultivation of farm crops. The events of

the past five years have accentuated the demand for wider investigation of problems dealing with increased production in all branches of national life, and in no field of agricultural research is there wider scope and greater possibilities than in plant breeding and in what is termed seed selection.

The problem of plant improvement has been attacked by different investigators in two ways, firstly, by pure selection, and, secondly, by the production of new varieties by artificial hybridization. The success attending efforts in the latter direction is a true measure of its importance. There does not at present appear to be any finality to the successful achievements of the hybridist, but the length of time involved in the production of new varieties is considerable, and although much may be achieved in the future we are at present chiefly indebted to the pure selectionist for the progress made in the last thirty years.

The history of the various systems of selection adopted by different workers on cereals is full of interest and instruction. In recent times two systems held the field—one, mass selection, and, later, partially as a result of the breakdown of mass selection, single plant selection. The procedure adopted by mass selectionists was to pick out from a crop the ears of the type it was desired to propagate. The grains from the selected ears were sown as one bulk, and from the resulting crop the ears most closely resembling the type required were again selected and the grain thereof sown as one bulk in the following season. After a few seasons the cumulative effect of selection was considerable, and a type was obtained which showed considerable advance on the general crop from which the ears were taken. When the selected seed was distributed to the general grower, and the influence of an annual selection withdrawn, the crop slowly deteriorated, and it then became necessary to repeat the work that had been performed at the expense of so much time and labour.

It was noticed quite accidentally, by one of the plant breeders at the Swedish seed station at Svalöf, that while the produce of mass selections was liable to considerable variation, and consequently in commerce must be regarded as unstable, that of individual plants varied extremely little. A number of single ear cultures were immediately started, and the character of the produce abundantly verified this observation. The evenness of the new cultures was so remarkable, and the produce in succeeding generations liable to so little variation (except where mechanical mixtures took place), that the recognition of the single plant as the unit of selection was quickly established. An extensive selection was then made amongst many varieties of cereals, when it was found that all were aggregates of definite forms which on isolation and individual propagation remained fixed in type. What we had been accustomed to call varieties were really aggregates of forms, and in order to reach our unit it was necessary to go further down in the scale and deal with what some authorities have called elementary species, and what Atterberg has designated A, B, C, and D forms.

To cultures raised from a single self-fertilized grain (or any other self-fertilized seed) Professor Johannsen has applied the title of *pure lines*.

The limitation of variability, with the consequent greater evenness of pure line cultivation, is, however, only a partial measure of the effect of raising cultures on a pedigree basis. A plant is possessed of physiological as well as morphological characteristics, and while selection may be conducted on the basis of the latter, the net effect is the isolation of forms showing a combination of the two.

Several instances of pure lines having identical botanical characters and differing in those of a physiological nature, such as strength of straw and earliness in ripening, have already been recorded, but an example may be of interest here. The writer made a number of selections of single ears of Archer barley in 1904, and the grains from each were sown separately in 1905. The produce of all the ears was identical botanically, but in ripening the produce of one ear was distinctly earlier than that of the others. Two selections, one approximating the average in time of ripening, and the early form, were propagated through several successive generations, and the distinguishing characteristic of earliness in ripening was maintained throughout.

Again, single ears of Chevallier (*H. nutans*) were selected and sown separately. The botanical characters were identical, and, with the exception that the grains from some selections were thinner than from others, there was nothing to indicate any botanical difference in the produce of the several ears. Attention was drawn to the plants raised from the seed of one ear, from the time they showed above the soil, by the very light green colour of the leaves, a feature which was permanent throughout the summer. The plants of this ear tillered more abundantly than those of neighbouring selections but were decidedly weak-strawed, and when the ears began to fill the straws adopted a semi-recumbent position from which they never recovered.

In view of what has been determined regarding the mixed nature of even élite stocks, such as those raised by Rimpau in improving rye, and by the investigators at Svalöf, it is not surprising to find that our cereal seeds as commonly cultivated are mixtures of many forms differing in all classes of characteristics.

In some cases the mixtures are caused mechanically in the ordinary course of commerce, but in others, such as the Scotch common barley in Scotland, and the Old Irish in Ireland, the seed of these so-called varieties has, through the course of generations and as a result of insular conditions, assumed the character of definite aggregates of forms.

During the past ten years the writer had a number of pure lines of Old Irish barley under observation, and by means of the density of the ear, the character of the rachilla, the presence or absence of setæ or bristles

on the first vein pair of the outer paleæ, and earliness and lateness in ripening, was able to identify *six* definite forms.

It may very naturally be asked what advantage is to be obtained by the grower by cultivating pure lines, as compared with mixtures, beyond stability of type and general evenness in the produce. One answer to such a query is that owing to increased industrial competition the buyer, whether wheat miller, oatmeal miller, or brewer, is more insistent in his demand for raw material of uniform quality. The producer must accordingly come into line with modern requirements if he wishes to secure the maximum price for his corn in the world's market.

Further, sufficient examples have been given above to show that if different physiological characters are in operation in the plants composing a crop, it is impossible to obtain evenness in ripening, without which a crop cannot reach its maximum quality. A simple comparison of ripe and unripe grain will also demonstrate that badly ripened grain is badly filled grain, and unless grain is well filled it cannot be giving its maximum yield.

The results of some experiments conducted in Ireland bearing directly on this subject are instructive.

Seed of a pure line of Archer barley was obtained from Denmark in 1906, and tested at twelve centres against the Archer then being sown in the experimental plots. The average yields of the two lots were:

Danish Archer	201 st. per acre.
Irish Archer	188 ,,
Difference	13 ,,

In 1907 a second test was made on the same lines, but in this case the Irish Archer was the produce of a number of hand-selected ears, and the average yields were:

Danish Archer	199 st. per acre.
Irish Archer	194 ,,
Difference	5 ,,

In 1908 a further test was made again on the same lines, but in this year the Irish Archer was the produce of a *single-ear culture* or, in other words, a pure line. The average yields were:

Danish Archer	180 st. per acre.
Irish Archer	178 ,,
Difference	2 ,,

The net result is thus that a difference of 13 st. per acre was reduced to 2 st. per acre, and at the same time greater evenness and better quality were obtained. This example illustrates the possibilities of improvement, but by no means marks a limit. The Irish seed used in 1906 was a particularly good commercial sample which had been kept under observation

and looked after carefully to prevent mechanical mixtures for a number of years, and with a less good sample a greater initial differance in yield would undoubtedly have been obtained.

In mixtures of broad- and narrow-eared barleys, when the former predominates, a considerable loss sometimes occurs by the broad-eared types becoming over ripe and the ears breaking off the straw. But apart from such causes as the above, a further factor may operate, namely, the difference in productivity and quality of distinct pure lines of a variety. An example of this is given in the *Journal of the Department of Agriculture and Technical Instruction for Ireland*, " The Improvement of the Barley Crop ", Vol. XIX, No. 2, 1919. Two pure lines of Archer were tested quantitatively for three years, and although the relative difference varies in the three years its direction was always the same, and one form was always superior in yield to the other.

The value of pure line cultures of barley is now fully appreciated in Continental countries, chief among which may be mentioned Sweden, Denmark, and France, where successful efforts have been made to propagate and distribute seed thus raised on a commercial basis. In Great Britain the matter has received attention at agricultural colleges and at the hands of private individuals and leading seed firms. In Ireland the Department of Agriculture and Technical Instruction, in collaboration with Messrs. A. Guinness, Son, & Co., Ltd., the celebrated brewers, have given the matter particular consideration, and have succeeded in propagating pure lines of Archer and Goldthorpe which are now grown in the barley-growing districts of that country to the practical exclusion of all the previously existing types.

The position in Denmark is strikingly similar to that obtaining in Ireland. There Archer and Goldthorpe have established themselves to the exclusion of all the older types. It is interesting to note that the pure Archer now grown in Denmark was selected from a small parcel of seed of that name obtained from a seedsman in the east of England, named Prentice. The name Prentice was retained by the Danish selectors, and it was only during a visit of a member of Messrs. Guinness' staff to Denmark that the identity of Archer and Prentice was established.

Reviewing the theory of mass selection in the light of what is now known of the behaviour of pure lines, it will be realized that mass selection might, if carried on for a sufficiently long period and under methods of rigorous selection, ultimately yield something closely resembling a pure line. The efforts of the selectionists have not, however, resulted in the production of a new type, but merely the elimination of undesirable types. The form they wished to arrive at was present from the commencement, and the full effect of their efforts was to accomplish, as a result of continuous selection operating over many generations, what it is now realized can be done by a single selection.

In the consideration of improvement by mass selection there is an explanation of what is commonly termed amongst farmers " degeneration ". Thus a bulk of seed (not the produce of a pure line) may produce a good crop one year, but gradually, by reason of mechanical mixtures or by the disproportionate increase of some of the more prolific forms, the numerical proportion of the different forms undergoes such a change as to alter the entire character of the crop.

INDICATION OF MATURITY

For reasons already dealt with it is important that barley should be fully ripe before it is cut. The straw of barley at the time of cutting, unlike that of oats or wheat, should be free from any trace of greenness, and when this stage is reached the grain will have assumed a finely wrinkled appearance. The longer the corn can be left during the final stages of ripening the higher will be the quality, but the length of such time depends to a large extent on the variety. Thus the straw of broad-eared barleys such as Goldthorpe and Standwell becomes brittle rapidly on ripening, and loss may be incurred by ears " necking " and falling to the ground, unless the crop is cut immediately such a stage is reached. With Archer the only change is that the ear when fully ripe assumes a position in which it is parallel to the neck with its apex pointing to the ground, and it will remain in this position for a considerable time without sustaining any loss.

At cutting time the grain should be quite hard, and, like the straw, free from any trace of greenness

HARVESTING

Twenty or thirty years ago it was customary to cut barley with a scythe, sickle, or side-delivery reaper and leave it in the swath for a few days, turning it at intervals. During this time the grain was in an alternate state of moisture absorbing and drying, as a result of which it matured and mellowed to an extraordinary extent. The nature of the chemical changes involved has never been clearly defined, but the evidence that has been collected indicates that there is a loss not only of contained moisture but of combined moisture also. The net result of these changes is that the interior of the grain first contracts, the skin thereupon becoming more finely wrinkled, and finally the interior assumes a very white, mealy appearance.

When the period in the swath was completed the barley was carefully raked together and stacked.

Changed economic conditions have resulted in the cessation of this practice, and barley is now generally cut with a binder in the same way as other cereals. Immediately after cutting it is stooked, usually in stooks of ten sheaves, and left in the open for seven to ten days or a

fortnight to mature. In some districts it is customary to " head " the stooks, that is, to invert other sheaves on those forming the stook, tying the head sheaves together at the bands.

From the stook the barley may be stacked, or, in wet climates, it may be built into small field " rickles ", about five to an acre, in which condition it is left to dry out for about a month or six weeks and then stacked. Under any conditions of harvesting the important point of all practices is to get the corn dry before it is stacked, otherwise overheating will occur, and the germination of the grain be thereby either partially or wholly impaired.

THRESHING

Except in a few isolated districts in the west of Ireland where the use of the flail still survives, barley is threshed by the now well-known steam threshing-mills, or mills of similar construction driven by water-power.

Sufficient has already been said regarding the process by which barley is converted into malt for proper appreciation of the necessity of avoiding damage which will impair the germinating capacity of the grain.

It has been found necessary in recent years, however, to call attention to the damage, and consequently reduced value of samples of malting barley, caused by careless threshing. In many cases the germ is removed completely from the grain, or damaged to such an extent that its germinating capacity is seriously impaired. When this occurs it will in addition be found that a very noticeable number of grains are cracked across, and that in others the skin is removed completely from the grain.

The effect of the removal or of injury to the germ is a considerably reduced quantity of soluble extract for the maltster. Further, moulds are very liable to develop on grains injured in any way, and these impart a most undesirable flavour to the malt, thereby reducing its market value.

Such damages as the above are readily traceable to the rapidly revolving drum of the thresher, or to the breast of the drum, against which the straw with the grain attached is beaten by the drum. The breast, which is in reality a wire screen shaped to a portion of the orbit of the drum, is capable of adjustment in such a manner as to allow of its being brought closer to the drum.

Injury to the grain is mainly caused by the breast being set too closely to the drum, so that the grain and straw as they pass through are rubbed with excessive violence against the breast; but it may also be caused in exactly the same way by too rapid feeding, when the grain is unable to pass through the apertures of the breast rapidly enough.

Both these causes are capable of such simple remedy that little excuse can be urged if they are neglected.

While threshing is in progress the straw should be examined frequently; if grains still adhere to the rachis the breast should be tightened slightly.

There is considerable difference in the way different varieties thresh; thus Archer is a particularly easy barley to deal with, but it is at times almost impossible to thresh Goldthorpe clean. The grains of this barley adhere to the rachis most tenaciously, but the latter is very brittle, with the result that portions of the ear with attached grain frequently pass through the thresher as "cavings" and are practically worthless. It is not an easy matter to adjust the breast of the drum in such a way as to prevent the grain being injured and at the same time to clear the straw of all grain, but the difficulty is one which it is hoped may be ultimately solved by the introduction of new varieties with less brittle rachides.

The screen of the steam thresher is usually a cylinder composed of spirally wound steel wire, the distance between the wires being capable of adjustment from the outside by means of a thread screw. As the width of the apertures is graduated from one end of the screen to the other, the corn, as it passes through, is separated into different classes according to the diameter of the grains. Each class of grain falls through the screen into separate hoppers and thence into separate sacks.

Evenness in size of grain is a most striking character and one thoroughly appreciated by maltsters. Grain of indifferent quality, if well screened, may be appreciated in value, and good grain, if badly screened, correspondingly depreciated. Consequently this is a feature of threshing that deserves some attention. Indifferent screening is often caused by feeding the machine too heavily, when the quantity of grain passing over the screen is too big for it to cope with efficiently. It may also be caused by grains being caught in the apertures of the screen and thereby choking it.

Before commencing threshing, the screen should always be fully opened so as to allow all grains caught between the wires to escape. A screen should never be tightened up when grain is actually running over it, as some corns are invariably caught between the wires, and as tightening proceeds they displace the wire, thereby making the apertures larger than they should be.

To avoid moulding on the malt floors the skin of malting barley should be as nearly entire as possible. It is a common practice to pass barley over the awner or haveller of the thresher with the purpose of removing the awn, and so giving the grain a better filled appearance. Unless the havelling is done carefully the top of the grain is frequently skinned, a condition which detracts from the market value of a sample. As far as the value of a sample for malting is concerned it is more desirable to have a portion of the awn adhering to the grain than to have the grain skinned, however little.

The quantity of barley capable of being dealt with by a steam threshing-mill varies with the size of the threshing-drum, and with the rate at which the mill is fed. An average output of carefully threshed grain is 40 to 50 qr. per day.

THE RELATIVE VALUES OF COMMONLY CULTIVATED NATIVE VARIETIES

Amongst the various experiments conducted with the object of ascertaining the relative commercial value of the many varieties of barley in cultivation, two, on account of their comprehensive character, may be regarded as authoritative.

One set of experiments was conducted in Denmark from 1883–1902, and the other in Ireland from 1901–11.[1] As the conditions in Ireland bear a close approximation to those prevailing in Great Britain, a short summary of the results obtained there is of interest.

The varieties under observation were Archer, Goldthorpe, Standwell, Scotch Chevallier, Hallett's Chevallier, and Old Irish, and the plots in which the tests were carried out were situated on farms in all the barley-growing districts. The samples from all the plots were valued as delivered in Dublin, and the monetary value per acre of each variety was ascertained on this basis yearly. In addition the nitrogen content of a sample from every plot was determined each year during which the tests were in progress.

The following tables show the monetary value and average nitrogen content of the varieties under experiment when compared with Archer.

COMPARISON OF AVERAGE VALUE PER ACRE OF ARCHER WITH OTHER VARIETIES

	Number of Tests.	Number of Years.	Average Value per Acre: Shillings.	Percentage Difference in Favour of Archer.
1. Archer .. .. .. Goldthorpe	67	8	182 168	8·3
2. Archer .. .. .. Goldthorpe .. .. Standwell	28	5	166 154 138	20·3
3. Archer .. .. .. Scotch Chevallier.. ..	25	3	179 163	11·0
4. Archer .. .. .. Old Irish	15	2	194 172	12·8
5. Archer .. .. .. Hallett's Chevallier ..	11	1	201 172	16·9
6. Irish Archer .. .. Danish Archer	28	4	190½ 190¾	0·11

[1] "A summary of experiments in barley growing, conducted during the eleven years 1901–11," *Journal Department of Agriculture and Technical Instruction for Ireland*, Vol. XIII, No. 1, 1912.

COMPARISON OF AVERAGE NITROGEN CONTENT OF ARCHER AND OTHER VARIETIES

	Number of Tests.	Number of Years.	Total Nitrogen in Dry Matter Per Cent.
1. Archer	66	8	1·53
Goldthorpe			1·52
2. Archer	24	4	1·56
Standwell			1·64
Goldthorpe			1·55
3. Archer	25	3	1·54
Scotch Chevallier			1·63
4. Archer	15	2	1·55
Old Irish			1·09
5. Archer	11	1	1·55
Hallett's Chevallier ..			1·66

The one clearly established result of these experiments is the high productivity of barleys of the Archer type, and, despite the fact that it is not what may be described as a very attractive barley, the nitrogen determinations prove that it is intrinsically good. Presuming the commercial values to be based on quality alone (the condition, &c., of all the samples from one centre being equal), the nitrogen figures show the valuer's judgment to be substantially correct with this exception, that Archer, by reason of its greyish appearance, was slightly undervalued. This in no way affects the general conclusions, but is an indication that an analysis, less empirical than commercial valuation, may bring to light differences of considerable value where least expected.

The correctness of the chemical valuation has been confirmed in a general way by the fact that in practice Archer has been found to be excellent malting material, easily worked and giving a good extract.

The only barley to approach Archer in value is Goldthorpe, and on heavy classes of soil and in late ripening districts the latter is probably the better barley. Among natural broad-eared varieties in cultivation in the United Kingdom, Goldthorpe is a barley of outstanding quality and produces the most attractive samples of grain.

None of the Chevallier types approached Archer in yield or in quality, and in point of strength of straw all the forms tested were decidedly inferior.

The Irish results are in most striking accord with those obtained in Denmark, where barleys of Archer type were again the most prolific. Goldthorpe was shown to be the best broad-eared barley, and Chevallier forms, between which no difference was established, were inferior to both. As a result of these tests Archer and Goldthorpe are to-day cultivated in Denmark to the almost total exclusion of any other type.

Since the completion of the investigations of which the above is a brief résumé, two new hybrid barleys, Spratt-Archer and Archer-Goldthorpe, have been raised and introduced by the Irish Department of Agriculture.

The hybridizing experiments were undertaken in the first place with a view to obtaining, if possible, a barley of the Archer type with the stiffer straw of Spratt, and in the case of Archer-Goldthorpe of obtaining a broad-eared form with a shorter neck. In so far as these characteristics are concerned the object of the hybridizing experiments has been attained.

At the same time it has been demonstrated by a series of field experiments, conducted in 1919 and 1920, that the Spratt-Archer is appreciably superior in yield to the parent Archer, while the grain is slightly brighter and consequently a more attractive barley.

The Archer-Goldthorpe also shows a superiority in yield to the parent Archer, but not to quite the same extent as in the case of the Spratt-Archer. It is distinctly stiff-strawed, and being short-necked there is little or no loss by ears necking off.

In point of quality this is a distinctly good barley, and on rich land should prove a most valuable type.

It will be seen from the above that the attempt to improve the yield of barley has been carried through three definite stages. There is, first, the substitution of Archer for those varieties most commonly grown previous to its extended introduction, such as Scotch Chevallier, Old Irish, and Hallett's Chevallier.

The Archer itself was then improved by the mass selection of good ears, and again by single-plant propagation of good forms. Finally the yield has been substantially increased by the introduction of a hybrid very similar in form to Archer, but possessing greater productivity and stronger straw.

YIELD OF THE CROP

The average yield of barley for the United Kingdom when compared with that of other European countries is considerably above the average, although it shows a distinct inferiority in this respect to Belgium, Holland, and Denmark.

Of the three kingdoms, Ireland returns the highest average yield of grain per acre, which may be in part attributed to the fact that barley in that country is most generally sown after a root crop, and to the soil and climatic conditions which promote a healthy and vigorous growth in the early stages of development. The tendency in Ireland is also to slow ripening, a condition which makes for well-filled and matured grain, and consequently heavy yields. Premature ripening, while not infrequent in Great Britain, is rare in Ireland.

The following table gives the average yield of barley in bushels and hundredweights for England, Wales, Scotland, and Ireland for the year

1914. The average yield of wheat and oats for the same year is appended for comparison:

	Barley.		Wheat.		Oats.	
	Bus.	Cwt.	Bus.	Cwt.	Bus.	Cwt.
England ..	32·90	14⅝	32·43	17⅜	40·01	14
Wales ..	31·50	14	28·32	15⅛	36·10	12⅝
Scotland ..	38·04	17	42·31	22⅝	40·18	14
Ireland ..	44·99	20⅛	38·34	20½	50·48	17½
United Kingdom ..	34·48	15⅜	32·77	17½	42·63	14⅞

A more extended comparison of the average yield of grain in England, Wales, Scotland, and Ireland, and in the United Kingdom is shown in the following table, which gives the yields in bushels and hundredweights.

Here again it will be seen that the average for Ireland and Scotland is appreciably above that for the United Kingdom.

YIELDS PER ACRE IN EACH YEAR FROM 1900 TO 1914

Year.	England.		Wales.		Scotland.		Ireland.		United Kingdom.	
	Bus.	Cwt.[1]	Bus.	Cwt.[1]	Bus.	Cwt.[1]	Bus.	Cwt.[1]	Bus.	Cwt.[1]
1900 ..	31·0	13·8	31·8	14·2	33·3	14·9	35·8	16·0	31·7	14·1
1901 ..	30·3	13·5	29·6	13·2	36·3	16·2	40·4	18·0	31·7	14·2
1902 ..	34·8	15·5	33·7	15·0	35·5	15·9	47·3	21·1	35·8	16·0
1903 ..	31·8	14·2	29·2	13·0	35·1	15·6	36·8	16·4	32·4	14·5
1904 ..	30·5	13·6	31·0	13·8	35·8	16·0	33·3	14·9	31·2	14·0
1905 ..	33·5	15·0	30·9	13·8	37·7	16·8	44·6	19·9	34·8	15·5
1906 ..	34·7	15·5	32·5	14·5	34·6	15·4	39·2	17·5	35·0	15·6
1907 ..	35·7	15·9	30·8	13·8	34·4	15·4	39·4	17·6	35·6	15·9
1908 ..	32·5	14·5	30·0	13·4	36·4	16·2	44·3	19·8	33·8	15·1
1909 ..	36·8	16·4	31·9	14·2	37·5	16·7	49·1	21·9	37·7	16·8
1910 ..	32·6	14·6	32·1	14·3	33·3	14·9	39·1	17·5	33·2	14·8
1911 ..	31·4	14·0	30·5	13·6	36·2	16·2	43·1	19·2	32·9	14·7
1912 ..	30·5	13·6	30·1	13·4	36·0	16·1	42·1	18·8	32·1	14·3
1913 ..	32·6	14·5	30·4	13·6	37·2	16·6	44·4	19·8	34·0	15·2
1914 ..	32·9	14·7	31·5	14·1	38·0	17·0	45·0	20·1	34·5	15·4

A very interesting series of figures is given in the following table, which shows the average yield of barley in the European countries and in the United States of America and Canada for the years 1909–13.

[1] 50 lb. to the bushel is the rate used for conversion.

The relatively high yield of Belgium and Holland is here emphasized, and these two countries are closely followed by Ireland. Denmark, Germany, and Norway succeed in the order in which they are given, with Great Britain immediately following as seventh on the list.

These figures emphasize the predilection of barley for the northern and north-western countries of Europe, that is, the countries of fairly temperate climates. It will also be noted that the area under barley taken as a percentage of ploughed land is higher in Great Britain than in any other European country.

	Average Yield per acre in cwt., 1909–13.	Area under Barley, as per cent of—		Area under Barley, average 1909–13.
		Ploughed Land.	Crops and Pasture.	
	Cwt.			Acres.
Belgium	21·7	3·1	1·8	84,331
Holland	20·5	3·4	1·3	68,220
Ireland	19·4	7·0	1·1	165,522
Denmark	18·2	15·4	8·3	585,137
Germany	16·3	7·2	4·6	3,944,506
Norway	14·6	15·3	1·5	88,754
Great Britain ..	14·5	17·2	3·7	1,679,248
Sweden	13·3	8·2	3·8	472,143
Luxembourg ..	12·9	1·2	0·8	2,820
Canada	12·1	3·8	1·7	1,500,657
Austria	11·9	11·8	6·1	2,691,174
France	11·1	4·0	2·2	1,865,512
Hungary	10·6	9·2	5·5	2,892,156
Bulgaria	10·6	7·5	5·3	618,707
U.S.A.	10·2	3·2	1·6	7,619,624
Spain	9·1	8·6	3·8	3,509,777
Roumania	8·1	9·0	7·1	1,318,678
Italy	7·1	2·2	1·3	612,813
Russia in Europe ..	7·0	10·3	8·1	25,396,382
Serbia	6·9	10·5	6·6	263,656

The following table shows, in hundredweights per acre, the average yield of the barley crop in England, Wales, Scotland, Ireland, United Kingdom, Denmark, and Belgium for quinquennial periods from 1875 to 1920. The striking feature of these figures is the increased yield recorded for Ireland and Denmark, in the case of the former country from about 1900, and in the case of the latter from about 1890. The reasons for this progressive increase in the two countries are probably several, but it is noteworthy that in both cases they synchronize with organized efforts on a large scale to improve the crop.

Thus in the case of Ireland the Department of Agriculture was established about 1900, and from that date until the present time that body has directed considerable effort towards improving the general cultivation and the quality of barley seed used in that country. The result of this effort is now evident in the distinctly improved yield of the crop.

In the case of Denmark definite efforts to improve the crop were initiated about 1880, from which year there is a decided indication of a general increase of yield per acre. A consideration of the yields from these two countries is further interesting, as in both cases the experiments conducted resulted in the establishment of barleys of the Archer type as being the most productive on the generality of barley soils.

STRAW

The quantity of straw produced per acre shows a distinct seasonal and varietal variation, but the average ration of grain to straw is approximately 1 : 1·25. Thus with a crop yielding 5 qr., or 1 ton of grain per acre, the weight of straw should be about 25 cwt.

On light soils and in dry districts where vegetative development is at about its minimum, the ratio will be a closer one, while the opposite applies in districts of larger vegetative growth.

Broad-eared varieties, such as Goldthorpe and Standwell, give a higher ratio of straw to grain than barley of the Archer type, as will be seen from the following table, which gives the yield of grain and straw of Archer and of two broad-eared varieties grown at four centres in Ireland.

WEIGHT OF STRAW AND GRAIN OF THREE VARIETIES

Farm.	Archer [illegible]				Goldthorpe				[illegible]			
	Weight of Grain per Acre.		Weight of Straw per Acre.		Weight of Grain per Acre.		Weight of Straw per Acre.		Weight of Grain per Acre.		Weight of Straw per Acre.	
	Cwt.	St.	Cwt.	St.	Cwt.	St.	Cwt.	St.	Cwt.	St.	Cwt.	St.
Farm No. 1, Co. Cork	19	5½	18	2½	19	6½	20	6½	—	—	—	—
Farm No. 2, Co. Cork	21	6	26	2	16	3	26	1	[illegible]	[illegible]	26	4
Farm No. 3, Co. Louth	21	1	34	7½	26	2	33	6	20	5	29	5
Farm No. 4, King's County	22	2½	27	4	20	3	25	0	18	3	23	5
Total	84	1	107	0	82	6½	112	1½	59	5½	77	7
Ratio of grain to straw	1 : 1·2				1 : 1·35				1 : 1·3			

COST OF GROWING

Previous to 1914 the cost of growing barley on average barley land was usually considered to be approximately £5 to £6 per acre.

The various operations chargeable against the crop include ploughing, sowing, harrowing, rolling, weeding, harvesting, carrying and stacking, threshing, carting grain to station, to the cost of which must be added the value of the seed, rent, value of unexhausted manures from the previous root crop, cost of artificial manure, if any are applied, and general expenses. The latter would include interest on working capital, rates, taxes, and insurance, upkeep of implements, fences, drains, and managerial expenses.

The various tillage and harvesting operations would account for approximately 50 per cent, and the value of unexhausted manures and artificial manures applied to about 20 per cent of the total cost. The balance of 30 per cent would account for rent and general expenses.

With the exception of rent the cost of all farming operations has increased very considerably since 1914. The proportion of rent to total cost is higher for cereal crops than for roots, but allowing for this the total cost of production has probably increased from $2\frac{1}{2}$ to $2\frac{3}{4}$ times, or from £5 per acre to £12, 10*s*. or £12, 15*s*., or from £6 per acre to £15 or £16, 10*s*.

During this period the value of barley and barley straw has likewise appreciated. Previous to 1914 malting barley sold at from 30*s*. to 45*s*. per quarter of 32 st., and in 1920 reached 120*s*. for the best samples and 90*s*. to 100*s*. for the average. Straw likewise appreciated from about 15*s*. to 20*s*., to 40*s*. or 50*s*. per ton.

It is extremely difficult, however, to arrive at a satisfactory average for the years 1914–8, or from 1918 to the present date, as prices have shown very considerable local variation; but generally speaking the enhanced prices realized for the crop have compensated for the considerably increased cost of production. For fuller information as to cost of growing, see article on THE COST OF PRODUCTION OF GRAIN CROPS (p. 303).

UTILIZATION OF THE BARLEY CROP

By far the greatest bulk of the British barley crop is grown with the idea of the produce being used in the manufacture of alcoholic beverages, such as ale, stout, and spirits; but in normal years, owing to a number of different causes, chief amongst which is unfavourable weather conditions, considerable quantities of the crop are unsuitable for this purpose.

Taking the acreage for 1914, which is officially returned at 1,871,169 acres, with an average yield of 34·5 bus., the total quantity of grain produced in that year was approximately seven million quarters. It is

difficult to arrive at the proportion of this total that is used for the purpose mentioned above, but in no probability is it more than 60 per cent of the total crop.

In most years the balance after allowing for seed is mainly used for cattle and pig feeding, for which purpose it is excellent material, occupying a position at least equal to that of maize.

The quantity of barley produced in the British Isles per annum is only about 50 to 60 per cent of the total quantity actually consumed in that period, either in the manufacture of alcoholic beverages or for feeding purposes, the balance being made up by imports. In this respect barley occupies a position between wheat and oats, the home production of the former being approximately 20 to 25 per cent and of the latter 75 per cent of the total requirements.

Owing to the fact that foreign barley may be malted at seasons in the year when the home product cannot be readily dealt with, for instance in the late spring with a rising temperature, much of the imported barley is utilized in this way.

With regard to the utiliziaton of barley straw, it has been pointed out previously that this is a crop which requires to be fully ripe before it is cut, consequently a greater portion of the food material which was elaborated in the leaf and straw will, by harvest time, have migrated to the grain, and the straw thus becomes nothing but a framework.

The feeding value of barley straw is consequently not very high, and in practice it is mainly utilized for bedding purposes.

From the British farmers' point of view barley is likely to continue to hold an important and economic position, for it is, firstly, an easy crop to grow in districts of low rainfall and on soils which are too light for wheat and oats in the generality of seasons. It is further a crop for which there is a ready market in most seasons. There was for many years past, and is still but to a slightly less extent, a wider range of price for barley than for any other cereal, a circumstance that remunerates the grower for extra care and management.

PRODUCTS OF BARLEY

By Prof. T. B. WOOD, C.B.E., M.A., F.R.S.

Barley.

The normal consumption of barley in the United Kingdom during the years 1909–13 was approximately 2½ million tons, of which about 1½ million tons were home grown and 1 million tons imported. Of the total consumption about 120,000 tons were used for seed. Brewing and distilling absorbed nearly 1½ million tons. About 50,000 tons were used for human food in the form of pearl barley, barley kernels, and similar products. The balance of nearly a million tons was consumed by animals, for the most part by pigs.

Since the normal consumption of concentrated foods by live stock before the Great War was about 11½ million tons per annum, barley formed about one-twelfth of this amount.

The average composition of barley as used for feeding is:

	Percentage Composition.	Digestible Nutrients, per cent.
Protein	11·0	8·2[1]
Fat	1·5	1·2
Carbohydrate	66·5	62·0
Fibre	4·5	2·5
Ash	2·5	—
Water	14·0	—
	100·0	

The nutrient ratio of barley is 1 : 9, the starch equivalent for production 71, and the number of food units 83.

Barley contains more fibre than wheat on account of the fact that the pale is adherent to the grain. In this respect it is intermediate in composition between wheat and oats. It is pre-eminently suitable for feeding pigs, for which purpose it is ground to meal and mixed with water, or with skim or separated milk or whey where these products are available. Nothing produces better pork or bacon than barley used in this way. It is also used to a small extent for fattening cattle and sheep. A mixture of equal proportions of crushed barley and decorticated cotton cake has been found particularly successful for sheep in experiments carried out by the Norfolk Chamber of Agriculture. In the East barley is largely used for horse corn.

[1] Containing pure protein 7·5 per cent.

Barley weighs, as a rule, rather under 56 lb. to the bushel.

Besides barley used as such, a considerable amount of barley by-products are used as feeding stuffs. A certain amount of what is known as barley bran results from the removal of the husk from barley in the manufacture of pearl barley and other preparations made from barley for human food, but the amount is small—not more than a few thousand tons a year—and most of it does not come on to the market, but is used in the manufacture of proprietary feeding stuffs.

Being composed largely of the husks of the grain, this barley bran is of relatively low feeding value, containing a high percentage of fibre, as shown by the following analysis:

	Per cent.
Water	13·0
Protein	10·5
Fat	3·5
Carbohydrate	50·5
Fibre	16·5
Ash	6·0
	100·0

Much larger amounts of what may be called barley offals result from the malting and brewing industries.

Malt culms or malt sprouts are the dried sprouts screened from barley in the process of malting. The annual production of this material is probably about 20,000 tons. Being composed of very young shoots it is exceedingly rich in nitrogenous substance, only about half of which, however, is true protein, the rest being amides.

Its composition is shown by the following analysis:

	Percentage Composition.	Digestible Nutrients, per cent.
Water	10·0	—
Protein (crude)	24·4	19·9[1]
Fat	2·0	1·5
Carbohydrate	42·8	30·9
Fibre	17·6	12·7
Ash	3·2	—
	100·0	

The nutrient ration is 1 : 3·9, the starch equivalent for production 43, and the number of food units 87.

A considerable proportion of the output of malt culms is used for manure on account of its high content of nitrogen. The rest is used as a feeding stuff, either directly or as a constituent of proprietary cakes and meals.

[1] Containing 12 per cent pure protein.

Brewers' and distillers' grains are produced in much larger quantities. They are the insoluble material remaining after the wort has been drawn off in the process of mashing and conversion. The annual production in normal times amounts to about 420,000 to 430,000 tons, reckoned as dried grains.

These grains are used either fresh or dried. Fresh grains have the following composition:

	Percentage Composition.	Digestible Nutrients, per cent.
Water	67·6	—
Protein	7·5	5·5[1]
Fat	2·8	2·4
Carbohydrates	14·6	9·1
Fibre	6·1	2·4
Ash	1·4	—
	100·0	

The nutrient ratio is 1 : 3·3, the starch equivalent for prodution 18, and the number of food units 30.

Fresh grains contain too much water and are too perishable to be suitable for transport to any considerable distance, consequently they are only suitable for use in the immediate neighbourhood of the brewery or distillery where they are made. As a rule they are used for feeding milch cows kept under town conditions. The usual ration is 20 to 30 lb. per head per day. Care should be taken to keep clean the mangers in which they are fed, for any wet grains allowed to accumulate will ferment and form objectionable products which may affect the milk directly or otherwise.

Dried Grains.

The drying of brewers' grains is a comparatively modern process, but the product has become popular and dried grains are now prepared in large quantities. Their composition is shown by the following analysis:

	Percentage Composition.	Digestible Nutrients, per cent.
Water	10·3	—
Protein	18·3	13·0[2]
Oil	6·4	5·6
Carbohydrates	45·9	27·6
Fibre	15·2	7·3
Ash	3·9	—
	100·0	

[1] Containing 5·2 per cent pure protein.
[2] Containing 12 per cent pure protein.

Nutrient ratio 1 : 3·8, starch equivalent for production 48, food units 77.

In composition they resemble wheat bran fairly closely, and indeed they may be used in place of bran, for most purposes replacing it pound for pound. They do not possess, however, the laxative properties of bran. They are commonly and successfully used for milch cows; for sheep, mixed with linseed cake; and to replace part of the oats for farm horses. In the latter case 5 lb. of dried grains replaces 4 lb. of oats.

There are several varieties of dried grains, known respectively as brewers' grains, distillers' grains, and ale and porter grains. The difference in composition of these varieties is not great, in fact probably not greater than the difference between individual samples of the same variety.

Barley Straw.

As in the case of wheat, the threshing machine delivers separately the barley straw, the chaff and awns, and the broken straw or cavings.

A large number of samples of these three products have recently been analysed at Cambridge with the following results:

	Protein.	Fat.	Carbohydrates.	Fibre.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Barley straw ..	3·3	1·8	42·4	33·9	4·6
,, awns ..	4·8	1·8	46·1	21·9	11·4
,, cavings ..	4·4	1·9	41·3	33·1	5·3
,, straw, digestible	0·8	0·6	22·5	18·3	—

No figures are available for the digestible nutrients of awns or cavings.

Barley straw, according to the above analysis, contains more protein, fat, and carbohydrates and less fibre than does wheat straw. As it is also considerably softer and more palatable, there is no doubt that it possesses a higher feeding value. Furthermore, barley straw frequently contains an appreciable proportion of clovers and grasses, which materially increase its feeding value. In root-growing districts barley straw usually forms the bulk of the dry food given to winter fattening cattle. It is sometimes chaffed and mixed with the pulped roots, but more frequently given long. This latter practice has much to recommend it. The cattle pick out the more palatable and nutritive constituents, namely the leaves, bits of clover, &c., and reject the stems, which are thus left for litter. If it is chaffed, on the other hand, the animals cannot exercise any selection, but must take it as it comes. Like all straws, barley straw is low in digestibility. Consequently it will serve to fill an animal and to help in his main-

tenance, but is little use for fattening or for producing work or milk. Even for these purposes it may be used up to the amount which will suffice for maintenance, i.e. about a stone a day for a 9-cwt. animal, which must, of course, be supplemented by more digestible foods such as roots, cake, meal, &c.

Beyond a ration of this amount, straw is practically useless.

The nutrient ratio is 1 : 70, the starch equivalent for production 19, for maintenance 43.

Barley Awns.

Barley awns, according to the above analysis, contain more protein and carbohydrates than the straw. They are, in fact, largely used for mixing with roots in the winter feeding of bullocks in many districts. For this purpose they possess the disadvantage of irritating the animal's mouth, nose, and eyes. This is mitigated by mixing them with roots, the dampness of which makes the awns limp and comparatively harmless. No definite information is available as to the digestibility of barley awns. It is therefore impossible to assess their real nutritive value in terms of starch equivalent.

Barley Cavings.

This material consists of the broken leaves of the barley, bits of clover leaf, and other of the more brittle constituents of the straw which are delivered separately in the case of most threshing machines.

As the analyses show, this material possesses more protein and practically as much fat and carbohydrates as straw. Where the barley at harvest contained much clover, the cavings are likely to contain more protein, in which case the feeding value may approximate to that of hay. In many districts the value of cavings is not recognized. They are regarded as straw which has been broken in the threshing machine and consequently spoiled. Though this may be true from the point of view of litter it is certainly not true from the point of view of fodder. In fact their very brittleness, which causes the threshing machine to separate them, is an index of low fibre content, and consequently of high feeding value.

No digestibility determinations have been made.

THE RYE CROP

By D. G. O'BRIEN, M.A., B.Sc., B.Sc.(Agric.), N.D.A.

In the British Isles at the present day, rye is only of minor importance as a cereal crop, though at one time it occupied a much more prominent place. The general displacement of rye, first by barley and then by wheat, is, however, of comparatively recent date.

In the days of Adam Smith, rye bread formed the cereal food of at least one-seventh of the population of the British Isles, and more than 1,000,000 ac. of rye were grown every year; but since that time the area under this crop has gradually decreased. In 1894 only 104,000 ac. of rye were grown, and early in the twentieth century the decrease in the acreage devoted to this crop was still more marked. In 1908 the area under rye had fallen to 53,000 ac., and in 1912 to 51,500 ac. During the Great War, with the impetus given to the production of home-grown cereals, rye growing became more popular, and in 1920 it is computed that 108,000 ac. were grown.

To a great extent this change in agricultural practice in Britain may be traced to the fact that the white wheaten loaf has secured first place in the favour of the public, and consequently there is little or no demand for rye flour for bread making. Were there not a very considerable demand for rye seed for catch cropping there would, no doubt, be a still further reduction in the annual acreage devoted to this cereal.

In parts of England and Ireland rye is fairly extensively grown as a catch crop, and fed off green to stock. This acreage, however, is not included in that shown under rye in the official crop statistics of the British Isles.

Very little rye, in comparison with wheat, is imported into this country for manufacture into flour. Indeed, in pre-war years it was estimated that the imports of rye were only equal to the quantity produced at home; so that, assuming that all the rye produced in and imported into this country was utilized for flour making, there was only available for food one-tenth of a bushel of rye per head of the population. The average

consumption of cereals per head of population per annum amounts to 9·5 bus. This again emphasizes the comparative insignificance of rye in the British Isles, both as a grain crop and as a human food.

On the other hand, in Russia, in Germany, and in the Scandinavian countries a relatively large acreage of rye is grown every year. In most of the North European countries rye bread (or, as it is called, "black bread") is highly relished, not only by the poorer classes, but by the whole population. This is especially true of Germany and Russia. For that reason these countries can now be regarded as the home of rye. In Germany in 1920 about 10,688,000 ac. of rye were grown as compared with only 3,413,000 ac. of wheat. Further, under normal conditions Germany is not self-supporting in the direction of her rye requirements. In Poland (i.e. Poland with her post-war boundaries) in 1920, 7,235,700 ac. of rye were grown compared with 1,790,000 ac. of wheat, giving a ratio of about 4 ac. of rye to every one of wheat. In European Russia with its pre-war boundaries it was estimated that the average annual acreage devoted to rye from 1914–8 amounted to 60,277,000 ac.

In Holland, Belgium, Denmark, and Sweden a relatively large acreage is under rye compared with that under wheat. In Denmark, Holland, and Sweden in 1920 about three acres of rye to every one of wheat were grown.

In France, as in the British Isles, there has been a great decrease in the average acreage under rye within the last fifty years; about thirty years ago about 4 million acres of rye were grown, but now there are less than 2 million acres, and there are five acres of wheat to every one of rye. In Spain the proportion is six acres of wheat to every one of rye; in the United States eleven to one; in the British Isles eighteen to one. If we take the world as a whole there were in 1920 approximately three times as many acres under wheat as under rye, but until as recently as 1910 it was estimated that there were less than two acres of wheat grown to every one of rye.

It is obvious from these statistics that the world's production of rye has greatly declined during the last century. This is due to the fact that, except in Russia, Germany, and in the Scandinavian countries, wheaten bread is preferred to rye bread. At the present day, however, rye bread constitutes the grain food of about one-third of the whole population of Europe, so that on that account rye must be considered of considerable economic importance. Further, although rye is not grown to any extent in the British Isles, the fact that it is so extensively grown on the Continent, and that rye and wheat are interchangeable as human foods, means that the price of rye will either favourably or unfavourably influence the price of wheat. In other words, the prices of wheat and rye to a certain extent are interdependent.

In the British Isles rye is mainly grown in England, and chiefly in the

eastern and southern counties. The chief rye-growing counties are Yorkshire, Norfolk, Suffolk, Essex, Nottinghamshire, Lincolnshire, and Hampshire. In Yorkshire in 1920 over 25,000 ac. were grown, so that about one-fourth of the total acreage under rye in the British Isles for that year was located in that county. In Scotland and Ireland very little rye is grown. The average annual acreage is generally between 5000 and 10,000 ac. in these countries.

The culture of rye dates back some 2000 years. Some of the early Roman historians, e.g. Pliny, mention rye, a new plant to the Romans, as being grown by some of the conquered " barbarian " races. This apparently fixes the origin of rye about the beginning of the Christian era, and therefore as being more recent than that of either barley or wheat.

Various theories in regard to the origin of rye are put forward, but there is no definite evidence to support any of them. The theory most widely held is that put forward first by Häeckel. He held that the original form of rye was *Secale montanum*, Guss., a species of rye which grows wild at the present day in mountainous countries bordering the Mediterranean and in some parts of Central Asia. This wild species has a jointed ear axis, and is a true perennial. It is thought that by cultivation both of these characteristics have disappeared.

On the other hand, De Candolle is disinclined to believe that any of the ryes, which are at present found growing wild in various countries, is the primitive form of rye. Some of these wild ryes, he thinks, may be ordinary ryes propagated from year to year by self-seeding, and in support of this he points out that rye, of all cereals, has developed a remarkable power of self-seeding. Other wild ryes are probably " rye-like " grasses.

There is only one species of cultivated rye, namely *Secale cereale*. The ryes belonging to this species in many of their characters resemble wheat. Rye, however, differs from wheat in many important aspects.

The ears of rye are rather longer, more slender, and more compressed than those of wheat. The ear axis or rachis bears two opposite rows of spikelets. Each spikelet is placed on a notch in the rachis, and is two- or three-flowered. Two of the flowers of each spikelet are perfect and produce grain, while the third is generally rudimentary. The empty glumes are very narrow. The flowering glumes are strongly keeled at their attached ends, are fringed with strong hairs along their middle line, and each is terminated at its free end by an awn of varying length.

The individual grains in the ears are partly exposed instead of being completely enclosed as in the wheat ear. The grain or caryopsis on threshing detaches itself from the glumes, i.e. becomes naked. In this respect it resembles wheat, but the grain is longer and more pointed at the base than the wheat grain. The medium longitudinal furrow so characteristic of the wheat grain is comparatively faint. The colour of the grain is

somewhat darker than that of wheat, generally being brownish grey or dull grey; the surface is slightly wavy or wrinkled; in texture the grain is exceedingly hard and tough, and is thus more difficult to mill than wheat.

Other peculiarities of growth of the rye crop are as follows. The spear, or first sheathing leaf of the embryo that appears above ground after germination of the seed, has a reddish-brown tinge which serves to distinguish rye from all other cereals, and especially from wheat. Further, the growth of rye in the late autumn and winter is characterized by profuse tillering, which serves to give an excellent cover to the ground. In late spring, when the ears are about to shoot, the leaves take on a characteristic greyish-green colour quite peculiar to the rye crop. The ears appear about ten to fourteen days before those of wheat. The plants lose their vitality a considerable time before the crop is ripe, and it seems possible that the stems function as leaves during the later stages of ripening.

VARIETIES OF RYE

There is a considerable number of varieties of rye, though few as compared with the varieties of other cereals. The explanation advanced for this is that rye cross-fertilizes very readily, and, further, it shows no natural tendency to vary from a fixed type. Again, plant-breeding stations, with the exception of Svalöf, have not greatly concerned themselves with the production of new varieties of rye. The attitude apparently of all concerned with plant-breeding has been that rye is of little economic importance, and on that account little effort has been made to improve the crop either by breeding or by selection.

The varieties can be classified into winter ryes and spring ryes, according to whether they are more suited to winter or spring sowing. The winter ryes are hardier than the spring ryes and have a longer growing season. In fact winter ryes are the hardiest of all cereals, and, on that account, they can be successfully grown in countries where the winters are much too severe for wheat or oats. As compared with spring-sown varieties, winter ryes give a flour of superior bread-making qualities. Further, they tiller very extensively, they are more productive, grow late into the autumn, and come away early in spring. Such ryes are frequently grazed, sometimes in November or December, and sometimes in April or May, even when grown as grain crops. For that reason they are much appreciated by stock owners, as they give valuable green food in winter and an abundance of the earliest green food in spring. However, this grazing, either in winter or in spring, must not be too severe, otherwise the subsequent yield of grain may be adversely affected. Light grazing on the contrary generally benefits the crop, in so far as it may prevent forward rye from shooting the ear before winter

is over, and in spring it may tend to consolidate the light ground and thus overcome the effects of drought.

As regards characteristics, other than those bearing on the time of sowing, which differentiate various varieties of rye, little is known. Varieties mainly differ from each other in such minor points as their yielding capacity, their power of tillering, and their hardiness. They cannot be distinguished from each other by any marked morphological peculiarities. The older varieties, however, generally have bluish-green or glaucous ears when unripe, which become yellowish grey when ripe, while some of the modern varieties have foxy-red ears and brown grains.

The following are the chief varieties of rye grown at the present day:

Winter or **Common Rye** is a very hardy but rather slow-growing variety. It ripens early, however, and is frequently sown as a forage or soiling crop, either alone or with vetches. It grows successfully even on very poor sandy soils. See Plate facing p. 100.

Giant Rye is a heavier-yielding variety, both as regards grain and straw, but it requires to be grown under better conditions of soil and climate than the preceding variety. It is also grown as a soiling crop.

Petkus is a Swedish rye produced at the Svalöf plant-breeding station. It is an extremely promising variety and is very extensively grown, especially in Sweden, Denmark, and America. In these countries it is one of the best grain-producing varieties.

Star Rye (Svalöf Stjärnräg) is another Swedish variety and is a selection of the older Petkus variety. It differs from Petkus chiefly in the nature of the grain, which is shorter, more plump, and better filled than the Petkus variety. The straw, like that of Petkus, is long and strong, the ears are of medium length, wide and compact at the base but tapering towards the top. The grain is of moderate size and generally of a light-red colour, although some samples are bluish in colour. It is a hardy variety, but to obtain good results it should be grown on heavier soils, and soils in better heart than those suitable for growing common rye. It is somewhat more prolific than the Petkus variety.

White Russian is an extremely hardy variety which has been observed growing successfully within the Arctic Circle. The straw of this variety may be fully 8 ft. long.

Danish Brattingsborg (Danish Brittany Rye) is an extremely productive variety, grown very extensively in Denmark, where it almost equals in productivity the Giant German rye, which is recognized as the heaviest yielding rye in Denmark.

Rosen Rye is a variety largely grown in America.

Mammoth White Rye is another variety, but it has no very distinctive characters.

All the above varieties are winter ryes.

The only spring variety of note in Britain is known as

St. John's Day or **Midsummer Rye.**—It is a small-grained variety, which, in districts with a good climate, can be sown as late as June or July, hence its name from St. John's Day, which falls on 20th June. It possesses marked tillering powers, and appears to be more closely allied to the wild species, *Secale montanum*, Guss., than any of the other varieties. It is a strong-growing variety, but the straw is somewhat soft. It proves more valuable when grown for forage or soiling rather than when grown for grain. When sown in June or July it can either be fed off to sheep or cut green, firstly in the autumn and secondly in the following spring. It may afterwards be allowed to mature, when it gives quite a good yield of grain and straw. If this variety be treated as a winter variety, i.e. sown from September to October, it loses its good qualities even when it survives the winter.

SOILS FOR RYE

In the British Isles rye is mainly grown on light, sandy soils, where the growing of other cereals is very precarious. Many such soils, in England especially, are very liable to suffer from drought during the spring and summer months; consequently cereal crops of all kinds are apt to be unremunerative. Rye under such conditions is the most productive and the safest grain crop to grow. Further, light soils in general are naturally sour, and rye withstands acid soil conditions more successfully than any other cereal. In some parts of Yorkshire rye is the only grain crop grown in the rotation, the land being considered too light and too poor for any of the other cereals. Again, on all light soils rye, being winter-sown and covering the ground more or less closely, prevents the extremely fine sandy particles from drifting or being blown away in spring.

It is rather unfortunate that rye has come to be regarded as a crop that should only be grown on poor, light, hungry soils, because there can be no doubt that rye might prove as profitable a crop as wheat, barley, or oats, if grown on good or liberally manured soils. Indeed some farmers, who have grown rye on good soils liberally manured, have found that the returns from rye are better than from any other cereal. Rye, therefore, can be grown on practically all soils. Heavy clay soils with much body, however, are not well suited to rye.

The main objection to growing rye on soils in good heart is that rye is more prone to lodge than wheat; but that difficulty can be overcome by taking rye in the rotation as a second cereal crop following barley, wheat, or even oats.

One essential condition for successful rye growing is that the soil must be well drained.

CLIMATE

Rye can be grown with success under a wider range of climatic conditions than any other cereal. It grows extremely well in very cold climates, and it is in such countries that it is mainly grown at the present day. Curiously enough, it can be grown equally well under more or less arid conditions. It has an extensive root system, and this enables it to withstand pronounced drought, such as is experienced in countries with a very low rainfall.

PLACE IN THE ROTATION

In this country rye is taken in a variety of positions in the rotation. (1) It may take the place of wheat, as for instance in rotations for light land. (2) In some parts of Yorkshire, e.g. in the neighbourhood of Escrick, it is the only cereal crop grown, and is there grown both after seeds and after roots or potatoes. (3) In other parts of the country it may follow barley or wheat as a second grain crop. (4) In some parts of East Anglia it is taken after lupines which have been ploughed in.

Abroad, rye may follow bare fallow, clover root, barley or wheat, roots or potatoes.

Although rye is not very often used in this country as a nurse crop for young seeds, it is stated that it is exceptionally useful for this purpose.

CULTIVATION

As soon as the land is clear of the preceding crop it is turned over with the plough. The depth of the furrow taken should be from 4 to 5 in. Rye requires a firm seed bed, and this is secured by comparatively shallow ploughing. There is generally no difficulty encountered in getting the land sufficiently dry for harrowing in August or September. After harrowing, the seed is drilled in, often on a pressed furrow, in rows 7 in. apart. The seed is then covered with a single stroke of the harrows and the ground left untouched till spring.

If rye be taken after lea the seed may be broadcasted on a pressed furrow and then harrowed lightly in. After a potato crop the seed is frequently sown broadcast on the surface after the potatoes are lifted, and then ploughed under with a very shallow furrow. The depth of furrow taken varies from 2 to 3 in. This method of seeding again ensures a firm seed bed.

In spring a good harrowing and a heavy rolling completes the cultural operations.

TIME OF SOWING

It is found that the best time for sowing rye is towards the end of August or early in September, though it may be sown as late as November. Early sowing, however, is essential if a good cover is to be secured before winter sets in.

With seed sown in August or September a quick braird is obtained, and under good conditions the crop may be so far advanced that it can be eaten down by sheep in December, but under less favourable circumstances it may not be ready for folding until spring. In both cases, after feeding the plants may be allowed to grow up and a grain crop taken. Rye is thus a dual-purpose crop. This grazing adds very considerably to the revenue derived from the crop, and may make rye growing an economically sound proposition on soils in good heart, because rye under such circumstances is a dual-purpose crop.

Another reason for early sowing is that on the light, poor, sandy soils it is essential that the crop should have as long a period as possible to establish itself before winter sets in. Tillering on poor soils mainly goes on in autumn and early winter, and if a good cover is not secured before winter the crop never recovers in spring.

In some parts of England it is customary to sow winter rye as late as January. This is considered advisable where winter rye is apt to be badly damaged by rabbits when sown earlier.

Spring varieties should be sown from March to May, but rye sown in spring is generally fed off green to stock

SEED REQUIRED PER ACRE

The quantity of seed sown varies from 2 to 3 bus. per acre, depending on the time of sowing, the method of sowing, and other factors, such as the tone and condition of the soil. When the seed is sown early 2 bus. of grain will give an ample cover, especially if drill sowing is practised. With late sowing and on poor soils 3 bus. of seed per acre should be used.

In some districts a small quantity (not more than ½ bus.) of winter vetches is sown along with the rye. The two crops are harvested together and the grain separated from the vetch seed by the screen of the threshing-mill. The vetch seed commands a good price, and the straw, which cattle in loose-boxes separate very efficiently from the rye straw, is of good feeding value. When the rye straw is used for thatch, the vetch straw is separated in the process of " pulling the thatch ".

MANURING

A light dressing of farmyard manure, up to 10 tons per acre, may be applied to the land previous to sowing the seed. Thus, when rye follows wheat or barley, farmyard manure is often applied to the stubble before ploughing, and similarly, when rye follows bare fallow, farmyard manure is often applied before the last fallow ploughing.

In some parts of Suffolk the practice is spreading of growing a crop of lupines and ploughing them down in preparation for a crop of rye. Under such conditions, and also when rye follows clover, no farmyard manure is applied to the crop.

It must always be remembered that rye straw under liberal manurial treatment is apt to lodge, and on that account rye does not generally receive very liberal manuring either with farmyard or artificial manures. There can be no doubt, however, that rye would repay much more liberal treatment, especially with artificial manures, than it at present receives. In applying artificial manures to rye several points should be borne in mind: (1) A readily available phosphatic manure like superphosphate should always be applied, as it encourages root development and serves to minimize the effects of drought; further, it enhances the value of the straw in that the straw is of a much whiter colour. (2) Potash manures should be applied to rye crops, as rye soils are generally deficient in potash, and its application in the form of kainit is advisable. (3) The least important manurial constituent for rye is a nitrogenous fertilizer. Too liberal dressing with a nitrogenous manure gives a dark-coloured straw which is apt to lodge, and this greatly depreciates the value of the straw. On that account every precaution should be taken to apply readily available nitrogenous manures in as small quantities as is consistent with good husbandry. Good husbandry demands a white rye straw, for a crop of good clean rye straw is at least as valuable as the yield of grain.

A satisfactory dressing per acre for rye would be 2 to 3 cwt. of superphosphate and 2 cwt of kainit, applied before the seed is sown. In addition $\frac{1}{2}$ to $\frac{3}{4}$ cwt. of nitrate of lime might be applied as a top dressing in spring or early summer if the crop is backward and is making only slow progress.

HARVESTING

Although rye is sown, comes into ear, and becomes yellow some considerable time before wheat, it is generally not ready for harvesting more than two weeks before wheat. Rye is peculiar in that the leaves and the straw become yellow some weeks before the grain in the ear is mature and the crop ready for harvesting.

The crop is cut with the self-binder whenever possible, but when rye is grown under good conditions, and a heavy crop is obtained, the straw is almost always more or less lodged, and considerable difficulty may be experienced in getting the binder to work satisfactorily. The straw may be 7 ft. or even more in length, and if it be tangled the binder frequently sticks and the sheaves when delivered are often not completely separated. Very often the reaper has to be used for cutting the crop, and the sheaves hand bound. Under ordinary conditions in this country, where only a moderate crop is obtained, rye stands up well and can be easily harvested with the binder.

The crop at the time of cutting must be thoroughly dry. After cutting, the sheaves are stooked, and when the rye grain is intended for seed purposes the stook is frequently capped or hooded. The crop can be carted in sooner than the other cereals, owing to its drier nature at the time of harvesting. The crop is stacked and threshed in a similar manner to other cereals. In some parts, however, threshing out of the stook is practised.

THRESHING

If the straw is to fetch its full price it must be threshed without any serious injury, and considerable care has to be exercised in the operation. For a long time after the flail had been abandoned for threshing cereals in general, it continued to be extensively used for threshing the rye crop. At the present day a special type of threshing-mill, known as a "beater", is often used. This machine has a long drum, about 6 ft. or more in length, which is provided with no pegs or teeth, such as are usually placed on the drums of threshing-mills. In place of pegs there are small corrugations on the surface of the drum.

In feeding such a mill the unbound sheaves are inserted lengthwise and not endwise, as is commonly the case when threshing other cereals. The straw on threshing is tied again into bunches and the bundles baled. The baling is often done by an old type of machine with an open top. The bundles are placed in the baler one by one and then trampled down. This method of baling the long intractable straw is extremely arduous. The bales as a rule weigh from 200 to 250 lb.

Another method of threshing sometimes practised is to thresh with an ordinary mill. The sheaves are fed in the ordinary way, namely, head first, but they are never released by the feeder. Only the heads of the sheaves enter the mill, in order that they may come in contact with the revolving drum and the grain be set free. The sheaves are then withdrawn by the feeder and retied by his assistant. This method of threshing is known in Scotland as "buffing off" the grain.

Rye straw is extremely valuable when perfectly white, properly threshed, and baled. Straw grown on high altitudes is superior in colour to straw

grown in valleys. Further, straw grown on wet, peaty soils or in wet years is much discoloured and of little value. A better, more bulky, brighter-coloured straw can be secured by cutting the crop a few days before it is dead ripe.

The grain must be thoroughly dry when stored in bulk, otherwise it becomes mouldy and musty more readily than other cereal grains.

YIELD

In the British Isles an average yield of rye would be from 25 to 35 bus. of grain per acre and about 30 to 40 cwt. of straw. Under good conditions the yield of grain may be as high as 70 bus. or even more per acre. The crop yields about 60 to 70 per cent straw and 30 to 40 per cent grain. The grain weighs from 56 to 62 lb. per bushel.

In respect to yield there is very little difference between rye and wheat. On good soils wheat will generally give a slightly higher yield of grain, but scarcely so much straw as rye.

UTILIZATION

Grain.

In the British Isles rye is not in much demand for manufacture into flour for bread-making, but in Northern Europe most of the rye grown is converted into flour. The world's production of rye in 1920 was estimated at 1,500,000,000 bus., and of this 800,000,000 bus. were grown in European Russia, 195,000,000 bus. in Germany, and 80,000,000 bus. in Poland. Thus in European Russia, Germany, and Poland more than two-thirds of the rye produced in the world is grown, and this rye is mainly used for human consumption in the form of "black bread". It is light, porous, dark in colour, sweetish in taste when fresh, but soon becomes sour on keeping. It is easier to digest than wheaten bread and probably more nutritious.

The milling of rye is similar to the milling of wheat. The flour is made by the roller process, as in wheat milling, but the subsequent separation of the offals from the flour is not so thorough as in wheat. All the offals are generally taken off in one operation, and these contain less protein and ash than wheaten offals. These offals can be very economically utilized in pig feeding.

The composition of rye and wheat is given in the table on the following page.

In composition rye grain closely resembles wheat, the chief difference being that rye is scarcely as rich in protein as wheat.

Rye is sometimes used for feeding to stock. As a food for dairy cows rye is not very suitable. It has been fed to cows in Denmark, and there

Composition of Rye compared with Wheat

	Water.	Protein.	Crude Fibre.	Carbo-hydrates.	Ether Extract.	Ash.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Rye ..	13·4	11·5	1·9	69·5	1·7	2·0
Wheat ..	13·4	12·1	1·9	69·0	1·9	1·7

it is said to have a deleterious effect on the quality of the butter. When so used it should be fed in small quantities, and it should be ground and mixed with coarse foods. Rye on being moistened swells up very considerably, especially if it has been stored, and, consequently, a considerable amount of risk is run in feeding rye to stock. However, if the rye is ground and fed with coarse foods the risk is considerably lessened

Rye can be used with advantage as a food for horses doing slow work, but in this case also the quantity fed in the ration must be small, especially if the horses are not accustomed to it, and the grain should be ground and mixed with coarse foods like bran or crushed oats. In horse feeding, however, it is safer to cook the rye, and if this be done it can be fed in the proportion of 1 part of rye to 2 to 3 parts of oats. Uncooked rye may cause digestive disorders under certain conditions. Rye is a very suitable food for pigs, especially when used as supplementary to whey.

In the British Isles much of the grain is used as seed for rye grown as a catch crop either alone or in mixture. The grain is also utilized to some extent in making alcoholic liquors, a certain amount of rye being used in the manufacture of whisky and brandy. Gin in Holland is made from rye.

Straw.

Rye straw, which may at times be up to 7 or even 8 ft. in length, is comparatively thin, but being almost solid is hard and wiry. As a fodder it is of little value, and practically none of it is now fed to stock. In composition it closely resembles wheat straw, to which it is somewhat inferior in feeding value.

It is utilized for a variety of commercial purposes. Until recently rye straw was used very extensively abroad for the manufacture of coarse brown paper, but at present wood pulp has replaced rye straw for this purpose. It is used for packing furniture, wine-bottles, and nursery stock. There is a considerable demand for rye straw for manufacture into straw goods, e.g. hats, baskets, beehives, for padding harness, and for brick-making. Rye straw is the best straw for thatching. Its stiff, tough character and its length make it invaluable for this purpose. First-

class straw always commands a good price as litter for high-class stables, and some horse owners will purchase it for this purpose, no matter what its price may be. On account of the variety of uses to which rye straw may be put, there is a ready market for good straw, and often the return for the straw is greater than the return from the grain. In fact the crop is often grown mainly for the straw.

Enemies.

Rye is subject to no specific insect or fungoid diseases, but pests like the eelworm, the wireworm, and the Hessian fly attack rye in common with other cereals.

Diseases.

Various forms of rust attack rye—a black rust on the stem and a red rust on the leaves are common. Smut may also affect rye. The best-known disease of rye is "ergot" or "spurred rye". Rye containing ergotized grain is extremely dangerous as a food for stock. It may cause abortion in pregnant animals, and also gangrene of the extremities.

Ergot is the dried sclerotium of the fungus *Claviceps purpurea*. The drug is imported chiefly from Spain and Russia. It is sometimes collected by picking from the grain by hand, but is more often separated by sifting.

DREDGE CORN

By W. BORLASE, N.D.A.

The cultivation of dredge corn—a mixture of barley and oats—has until recently been mainly confined to Cornwall. Its more general adoption as an ordinary crop of the rotation was accelerated during the years 1917–8 by the relaxing of the restrictions with regard to its use as food for stock, the feeding of dredge corn to stock having been permitted while neither of its constituents grown alone could be so employed.

In the Annual Agricultural Returns of the Board of Agriculture for Cornwall, one finds all the various cereals named with the acreage of each, but no mention of dredge corn occurs till 1919, although the area devoted to this crop has for some years been greater than that of barley alone in this county. In the returns, dredge corn formerly was entered as barley by most farmers.

The origin of the name "dredge" (often pronounced "dradge") is not very obvious, but its common use applied to corn crops seems to

indicate a mixture; thus a farmer speaks of " dredging " his oats or barley with a little wheat, &c., but dredge corn is always understood to be a mixture of oats and barley in varying proportions according to the nature of the soil, aspect. or the use to which it is to be put.

Place in Rotation.—The commonest rotation in Cornwall is a seven-course one as follows: (1) wheat or oats, (2) oats or wheat, (3) roots, (4) barley, (5) seeds, (6) grass, (7) grass. Dredge corn will usually take the place of oats, and very frequently that of barley as well, unless the soil, climate, and situation are very favourable for the production of a high-class sample of the latter, which, in a county with a rainfall of nearly 40 in. and soils deficient in lime, is not often the case.

In some cases the rotation followed is: (1) roots (generally mangels), (2) cereal crop, (3) cereal crop, (4) roots, (5) cereal crop, (6) seeds, (7) grass, (8) grass, (9) grass—the second and fifth years' cereal crops being dredge corn.

In the west of the county many of the dairy farmers dredge all their corn crops, the whole of the grain being consumed on the farm by pigs and cows.

When it forms the first crop after the breaking of the lea, it is usual to add a small proportion of spring wheat to the mixture, and of late years this custom of growing a mixture of the three cereals has become fairly common in some districts.

The proportion of oats to barley is generally two of the former to one of the latter, though this will depend largely on the soil. In many districts when equal quantities of the two cereals are sown, the oat will be the predominant plant, but, after a field has been limed, barley will be much more abundant and of stronger growth than the oat. On some soils this effect of lime on the oat is seen for many years, so that it is necessary to sow a larger proportion of this grain to secure a moderate amount at harvest.

On the other hand, one farmer informed the writer that he had to sow two bushels of barley to one bushel of oats to secure a proportion of two of oats to one of barley at harvest. Probably his soil is very deficient in lime.

Mr. W. Payne, of Lelant, in the west of the county, furnishes some interesting information respecting the custom of his district. He says: " Under ordinary circumstances dredge corn on lea ground (after grass) will consist chiefly of oats; after roots it will be of about the proportion sown with a tendency in favour of the oats, whilst for the last or ' seeding out ' corn crop the barley will be the predominant factor. I prefer white oats with barley for the seeding out crop, especially if a dressing of lime has been applied recently with the object of benefiting the grass seeds, as I find the white oat does not feel the application of lime so quickly as the black oat."

The stronger growth of barley, and its greater abundance in the seeding out crop, coming after roots is probably due to the reduction of organic matter with its acids through the thorough cultivation and aeration of the soil for three years.

Another farmer from the same part of the county speaks of the advantage gained by sowing a mixture of white and black oats in preference to either alone. A very heavy crop usually results, and the stronger-growing white variety supports the finer-strawed black oat, and the mixture of straw gives a larger amount per acre than the black alone would do.

Time of Sowing.—The crop is usually sown in the first or second week in April according to the season and the locality; in many parts the middle of April is not considered late, but in the colder districts of greater altitude in East Cornwall, the farmer likes to get his seed in and covered by the first week of April.

Seed required per Acre.—The amount of seed sown is generally about $4\frac{1}{2}$ bus. to the acre—3 bus. of oats to $1\frac{1}{2}$ bus. of barley—but frequently it is a little heavier, especially on strong land. The Cornish farmer holds the opinion that thick seeding is necessary on rich land: with a larger number of plants on a given area there is greater competition for the available plant-food. The crop is consequently not so rank and heavy, and is not so easily beaten down by wind and rain.

Manuring.—The manure applied is usually phosphates only, either dissolved bones or superphosphate, but in colder districts 1 cwt. per acre of sulphate of ammonia proves useful in pushing on an early growth, while it is insufficient to delay ripening. Where the dredge corn forms the seeding-out crop, a slow-acting phosphate, as bone meal, is frequently applied for the benefit of the " seeds ", but in too many cases the farmer still allows the manure merchant to decide for him what fertilizers are best, and sows 4 to 5 cwt. per acre of corn manure.

At one time a heap of mixed manure was made (dung, earth, and sea sand), and about twenty loads to the acre ploughed in. The high price of labour has caused this practice to become unpopular, but farmyard manure is still applied by a few farmers for this crop. Their method is open to criticism, for, as the dung is not ploughed in until the spring, the light thin soils are made so loose and open that they dry rapidly, and neither corn nor seeds do well unless the season is a damp one. The use of artificial fertilizers is consequently generally adopted.

BENEFITS FROM GROWING DREDGE CORN

The advantages of dredge corn over either barley or oats alone are fairly numerous and evident. In the first place, a larger amount of grain is produced than would be secured from barley alone, and, very frequently, greater than would be produced from oats alone. Most

authorities are agreed on this, and Mr. Payne adds an interesting note: "When we get a dry spell, as we did in 1918, at the end of June or the beginning of July, the 'creased' or tillering stalks of the oat plants die away, the barley gains the mastery and fills up the blank spaces; this was very conspicuous last season when many pure oat crops were thin and light." Farmers are also of the opinion that a better sample of corn is produced by growing the two together, the ripening being more regular. The fact that the oat is rather deeper-rooted than the barley, so that a deeper layer of soil is being drawn upon for food, may account for the larger total of grain being produced, and the heavy seeding prevents over feeding by either of them, and the consequent production of a more uniform and superior sample of straw and grain.

Another advantage is the production of straw of higher feeding value. Barley straw is poor food for stock where the grain is well ripened, and where the oat is grown alone the straw is often very coarse. When grown together the mixture is less coarse, and the crop being cut at an earlier period than barley grown alone, the straw is of higher feeding value and is readily eaten by stock.

A third advantage is the greater probability of the crop withstanding the pressure of wind and rain in the month of July, and doubtless this was one of the chief reasons which led to the introduction of this crop on Cornish farms. It frequently happens that storms of wind and rain prevail in this month, with sometimes a rainfall of over 5 in. for the month, and the corn crops are prostrated. Dredge corn is believed to stand better than either oats or barley grown alone, and this is in itself a sufficient reason for growing it, especially where stock is kept to which the grain may be fed.

The mixture of the two grains is considered by most farmers to make a better balanced food for farm stock generally than either alone, though this is at least questionable. It can hardly be shown that a grain with such a large proportion of indigestible fibre as the oat can be an economical food for the pig, while the oat is certainly a better food for the horse than barley. For young or fattening bullocks, possibly the mixture is superior to either alone. The albuminoid ratios of the digestible portion of each are as follows:

Barley	1:9·5
Oats	1:6·5
Dredge Corn (2 oats to 1 barley) ..	1:7·5

The oat is rather richer than barley in mineral matter or ash and much richer also in fat, the barley being noted for its high percentage of starch.

In the last place it should be pointed out that many Cornish soils are peculiar; on some, barley does not succeed; on others, the oat crop

is often a failure. The reason for such want of success is not always apparent, but frequently lime is doubtless the determining factor.

The farmer takes the safer course by sowing the mixture. He does not, in many cases, know the imperfections of his soil, neither can he foretell the nature of the coming season, so that he minimizes risks by sowing the mixture of the two cereals. Looked at from this point of view alone the practice has much to commend it, and its adoption by other counties may be anticipated when its advantages become better known.

Yield per Acre.—The amount of grain produced per acre by dredge corn is usually from 18 to 20 Cornish bushels of 130 to 140 lb. per bushel. Of barley alone, 12 to 14 bus. of 8 score per bushel is considered a very fair crop. The weights of straw will be nearly twice as great with the former as with the latter.

Some farmers are now adding a little wheat to the mixture—the spring variety, April Bearded, being generally selected for this—and the majority of such growers consider this an improvement, the crop standing well and the grain forming a food which is valuable for all varieties of stock. Linseed also has of late been added by a few farmers.

THE BEAN CROP

By JOHN PORTER, B.Sc.

Beans have been grown as a field crop from very early times and can be traced back to over a thousand years before Christ. In fact the reference to beans in 2 Samuel, xvii, 28, probably dates to 1023 B.C. Beans are also referred to in other Old Testament books, e.g. Ezekiel.

The lake dwellers of Switzerland and northern Italy in the Bronze Age are said to have cultivated beans.

The bean was a well-known plant in Ancient Egypt, and apparently was introduced into China a little before the Christian era and somewhat later into Japan, though it appears to have been grown in the higher Himalayas from the very earliest times.

Its origin is a matter of considerable speculation, but De Candolle concludes that the bean plant was introduced into Europe probably by the Western Aryans at the time of their earliest migrations. He suggests that its wild habitat, several thousands of years ago, was twofold, viz. (1) south of the Caspian, and (2) north of Africa; further, that its area has been in a process of diminution and extinction for a very long time, seeing it has no means of dispersing its own seeds nor any means of protection, such as spines, &c., against various animals which eat it. Under these circumstances it seems quite obvious that the wild bean plant would gradually have tended to disappear more or less had it not been rescued by man for purposes of cultivation.

Beans were used at pagan funeral ceremonies, and all kinds of superstitions led the mourners to see letters and characters indicating death or some other calamity marked on the characteristically zygomorphic flowers.

Beans are said to have been introduced into Britain by the Romans, and it is interesting to note that the generic name of beans (*Faba vulgaris*) is believed to have been derived from the patrician family of Fabius.

The bean crop has been a most important crop on farms in the British

Isles for many centuries. It was cultivated under the old feudal system, and since the days of enclosed fields it has been a valuable crop in this country.

Although peculiarly suitable for stiff clay soils containing a sufficiency of lime, beans and peas were the chief crops used in the rotation between two cereal crops on all classes of soil, previous to the introduction of clover and root crops into farm rotations about the middle of the seventeenth century.

After the introduction of clover and roots into farm rotations the acreage under beans decreased rapidly on the lighter and medium soils, more especially in the latter part of the nineteenth century, until the area grown in Great Britain fell to approximately a quarter of a million acres, or about half of that grown in the seventies, as the following table shows:

ACREAGE UNDER BEANS

Year.	England.	Scotland.	Wales.	Great Britain.
	Acres.	Acres.	Acres.	Acres.
1868 ..	503,700	22,423	3777	529,900
1869 ..	548,257	23,003	3944	575,204
1912 ..	275,729	8,421	1272	285,422
1916 ..	235,080	5,440	1177	241,697
1920 ..	255,068	5,726	2074	262,868

In Ireland the acreage under beans in 1869 was 9957 ac., whereas in 1912 it had dwindled down to 1421 ac.

Although the acreage under beans has diminished so much in the last half-century, beans are still a very popular crop on the more tenacious soils, and in favourable seasons produce very satisfactory crops of both grain and straw.

Curiously enough, about half the acreage under beans in Great Britain is concentrated into about eight of the south-eastern counties of England, as is shown in the following table. As counties vary in size and in the amount of arable land, it is felt that readers will appreciate data showing the percentage of arable land devoted to beans in these bean-growing counties.

In Lincolnshire (Lindsey), Norfolk, and Lincolnshire (Kesteven) it will be noted that there is a fairly big acreage of beans, but this crop is only occupying a small proportion of the arable land in each of these county administrative areas.

The county which has the largest area under beans is Suffolk with 38,536 ac., making 6·8 per cent of the arable land of the county. This is followed very closely by Lincolnshire with 36,487 ac. under beans,

Acreage under Beans in Certain County Administrative Areas

Taken from the Agricultural Returns of 1915

County Administrative Area.	Acreage under Beans.	Total Arable Land.	Percentage of Arable Land under Beans.
	Acres.	Acres.	
Essex	30,725	507,034	6·0
Suffolk (East)	24,875	327,392	7·6
Lincolnshire (Lindsey)	15,388	549,103	2·8
Suffolk (West)	13,661	236,784	5·7
Cambridgeshire, excluding Isle of Ely	12,195	212,424	5·7
Bedfordshire	11,074	144,025	7·6
Lincolnshire (Holland)	10,617	178,477	5·9
Northants, excluding Soke of Peterboro'	10,571	156,817	6·7
Norfolk	10,564	780,687	1·3
Lincolnshire (Kesteven)	10,482	266,531	3·9

being 3·67 per cent of the arable land. Then comes Essex with the figures given above.

CHARACTERS OF BEAN PLANTS

Beans belong to the natural order Leguminosæ, and one important characteristic of this order is that the plants bear legumes or pod fruits the seeds of which are used for food all the world over. The cultivated beans of this country belong to the genera Faba and Phaseolus, although other genera are grown in tropical countries.

The great botanist Linnæus placed the common field and garden beans under the same genus as vetches (Vicia). The common bean plant, however, differs from the vetch in possessing (1) a strong unbranched stem capable of supporting the plant generally in an erect position, and (2) a pod or legume which in its early stage is fleshy, with a thick velvety lining; consequently the bean plant was placed under another genus called Faba, the common species of bean being called *F. vulgaris*.

The plant of the common bean (*F. vulgaris*) has usually a thick stem or haulm, square in section, bearing compound leaves, while the flower clusters spring from the axils of each of these leaves. Hence in favourable seasons clusters of pods are found on almost the entire length of the stem.

The seed has a tough leathery skin inside which are two large fleshy cotyledons, or what after germination become the seed leaves. It also

BEANS FROM DIFFERENT VARIETIES

Part of a Bean Plant

[*Vol. I, facing p. 272*

possesses a well-defined scar or "hilum" which shows where the seed was attached to the pod. This scar is generally black, but in certain varieties may be white.

The root is a long, strong tap root, which, in common with the roots of other leguminous plants, develops on its rootlets wart-like growths or "nodules". These are caused by the invasion of a soil organism called *bacterium radicicola*. Strangely enough, these nodule-forming bacteria do not harm the bean plants, but the joint-life, or symbiosis, actually enables them to fix and utilize atmospheric nitrogen for their own development, thus rendering the plant to some extent independent of artificial supplies of nitrogen.

VARIETIES OF BEANS

The common bean (*F. vulgaris*) is divided into two groups, viz. field beans (*F. vulgaris arvensis*) and garden beans (*F. vulgaris hortensis*). The French bean (*Phaseolus vulgaris*) and the Runner bean (*P. multiflorus*) are also two main groups of the genus Phaseolus. In all these cases many varieties have now been raised by progressive seed growers, but it will be sufficient for this article to enumerate a few good varieties.

Field Beans (*F. vulgaris arvensis*).—The chief varieties under this head are (*a*) Scotch horse bean, (*b*) Tick or English horse bean, (*c*) Russian or winter bean, (*d*) Heligoland bean, (*e*) Mazagan bean.

Scotch Horse Bean.—This is a hardy spring-sown variety, grown chiefly in the north of England and in Scotland. It is adapted to heavy clay soils or alluvial soils that are well drained. The stem grows 3 to 5 ft. high, and well-grown specimens carry pods fully half-way down in a good season. The seeds are about ½ in. long by ⅜ in. wide, slightly flattened on the sides, and somewhat wrinkled or pitted. The new seed is generally light brown in colour, but tends to become dark or even black when badly harvested and heated in the stack. The eye or hilum is generally black. The average bushel weight is from 60 to 66 lb. In some districts in Scotland this variety goes under the name of the Carse bean, in others the Kilbride bean.

The Tick or English Horse Bean.—This is the common field bean in the south of England, and may be grown on lighter land than the Scotch horse bean. It is a prolific variety, but comparatively short in the straw (3 to 4 ft.). The pods and seeds are smaller than the Scotch horse bean and the seeds rounder. It is regarded as a valuable feed for horses, and usually commands a higher price per bushel than the Scotch horse bean. The bushel weight may be 64 to 70 lb.

Russian or Winter Bean.—A hardy variety which is autumn sown in the Midlands and in the south of England. It thrives on medium soils. The straw or haulm is short (3 to 4 ft.), and in a good crop pods almost

down to the ground. It can be harvested in July and August with the result that it escapes to a large extent the attacks of the bean aphis, or, as it is sometimes called, dolphin.

The seed resembles the Tick bean, being plump and heavy, weighing on an average 64 to 70 lb. This variety is said to have been introduced about 1825, and it has proved itself to be very popular indeed.

Mazagan Bean.—An early variety grown as a field crop in the south of England. The stems are comparatively slender and fairly tall (4 to 5 ft.). The pods are long and narrow, and the seeds are about ¾ in. long, with slightly flattened sides. This is also used as a garden variety.

Heligoland Bean.—A hardy, prolific, and early variety, suitable for growing in late districts. It has a medium length of haulm and is proving a rival of the Mazagan, both as regards cropping power and earliness. The average bushel weight is 65 to 70 lb. Other varieties of importance are the Granton bean, the Red bean, the Cluster bean, the White Spring bean, and the Round Spring bean.

Garden Beans (*F. vulgaris hortensis*).—The garden bean is a very strong-growing plant. The pods are much longer than in field beans, the seeds larger, flatter, and more wrinkled after drying. They may be "white" seeded, e.g. Long Pods, Giant Windsor, Early Long Pod, and Mazagan; or "green" seeded, e.g. Green Giant, Green Long Pod, Green Windsor, and Dwarf Green Gem.

Kidney, French, or Haricot Bean (*P. vulgaris*).—An annual plant with dwarf and bushy habit. The wild prototype does not appear to be known, and, although there is much speculation as to the country in which it originated, it appears probable that it is of South American origin.

In Britain it is used chiefly as a green vegetable, and for this purpose the pods should be gathered when they are green and crisp.

Useful varieties are Canadian Wonder, Negro, White Haricot, Superlative, Satisfaction, &c. Some varieties have climbing stems.

Scarlet Runner (*P. multiflorus*).—Closely allied to the French bean, but has a climbing stem which twines round a support in the opposite direction to the sun. It is grown chiefly as a tender annual. The usual colour of flower is scarlet, but other colours may be secured. The pods are picked and used in the green state as a vegetable.

The ordinary Scarlet Runner is most commonly grown, but other useful varieties are Best of All and Painted Lady.

The remainder of this article is intended to apply more particularly to the cultivation of field beans, although the general principles involved apply equally to garden beans.

SOIL AND CLIMATE

Field beans can be grown on a great variety of soils, but they are peculiarly adapted to " strong " land; in fact, the present-day designation of wheat- and bean-land implies that the land is anything from a clay loam to a strong clay soil.

It is not usual to sow winter beans north of the English Midlands, largely on account of the winter weather being more severe; hence north of the English Midlands and in Scotland, where beans are grown, they are sown in the spring months of the year, usually March.

PLACE IN ROTATION

Beans generally come between two cereal crops in the rotation of cropping, or between a cereal crop and a bare fallow, as will be seen from the following rotations:—

1. *Heavy Clay Soil.*

1st year	wheat.
2nd ,, ...	beans.
3rd ,, ...	fallow.

In some cases, an occasional fallow would be taken instead of one every third year.

2. *Essex Six Course.*

1st year ..	wheat.	4th year ..	fallow.
2nd ,, ..	beans (winter).	5th ,, ..	oats.
3rd ,, ..	wheat.	6th ,, ..	clover.

3. *East Lothian Six Course.*

1st year ..	wheat.	4th year ..	beans (spring).
2nd ,, ..	seeds, hay.	5th ,, ..	wheat.
3rd ,, ..	oats.	6th ,, ..	roots.

4. *Scotch Eight Course (Stiff Soils).*

1st year ..	wheat.	5th year ..	barley.
2nd ,, ..	beans (spring).	6th ,, ..	seeds hay.
3rd ,, ..	wheat or oats.	7th ,, ..	oats.
4th ,, ..	turnips or fallow.	8th ,, ..	fallow.

CULTIVATION, SOWING, ETC.

It is very essential that the land should be properly cleaned before beans are sown and that it should be kept as clean as possible after. Another point of importance is that farmyard manure has a great effect on

this crop. With these two points in mind, the following typical cultivations will be easily followed.

1. *Spring Beans grown in "Raised" Drills following a Cereal Crop in the North of England or Scotland ("Drilled" Beans)*.—Immediately after harvest, harrow the stubble if possible to germinate weed seeds; plough say 6 in. deep in November, and leave to weather during the winter months. As soon as the land is sufficiently dry in late February or March, plough again, harrow, and roll to get a fine tilth; open drills 27 or 28 in. wide with the double mould board plough. Apply 10 to 16 tons of farmyard manure per acre and spread in drills. At the same time 4 cwt. superphosphate and 2 cwt. kainit may be sown on the dung. The beans are then sowed by hand at the rate of 4 bus. per acre, and covered in by splitting the drills. Roll the drills to firm the soil and facilitate rooting of the young bean plant. Just before the beans push through the soil, harrow with a light harrow to break up any crust that may have formed, as well as to destroy any surface weeds that may have germinated.

After the beans have pushed through, frequent horse hoeings between the drills and occasional hand hoeings will be necessary to keep the weeds down and encourage the beans to grow rapidly. As soon as the beans close the drills up more or less and begin to flower, the cultivation should be discontinued; otherwise the bean plants would be injured by the horse hoeing. The beans are now left to ripen.

2. *Spring Beans grown on Ordinary Ridges, Lands, or Feerings*.—The autumn cultivation would be the same as in the preceding case, except that the dung would be ploughed in, if possible, in the autumn. In late February or March, when the ground gets sufficiently dry, the land should be cultivated and harrowed to get a sufficiently fine surface tilth for drilling. The beans may then be drilled with an ordinary three-coulter pea and bean drill, say 27 in. apart, or in some cases with an ordinary "corn" drill by stopping up alternate coulters, making the drills about 14 in. apart. In either case inter-cultivation would be possible during the spring and summer months.

When the beans are broadcasted by hand, inter-cultivation is much more difficult and often impossible.

3. *Winter Beans after a Cereal Crop (Midlands and South of England Counties)*.—As soon as the cereal crop has been harvested, the stubble should be harrowed to germinate weed seeds; and if the land is at all weedy it should be cleaned as much as possible in the late summer and early autumn. A dressing of farmyard manure (10 to 15 tons per acre) should be given and ploughed in during September, and the seed drilled or dibbled in, say 14 in. drills at the rate of 2 to 2½ bus. per acre.

As an alternative method of sowing, the seed may be sown by hand or with a special bean drill attached to the plough in alternate furrows. In the latter case a light furrow of 3 in. deep would be sufficient. Where two pairs

of horses are ploughing the bean land, one pair would have the ordinary plough and the other the combined plough and bean drill in order that the latter may sow continuously. The land may or may not need harrowing, depending on the condition of the soil, and may then be left till spring.

In late February or early March, according to the weather and condition of the soil to carry the horses, harrow the land to break the crust that has formed on the surface soil. Inter-cultivation may then be given to keep the land clean for so long as these operations do not injure the plants.

HARVESTING AND YIELD

Harvesting.

Winter beans will be ready to cut in late July or August, but spring beans will not be ready till September. Beans should be cut when the leaves have fallen off, the stems ripened, the pods blackened, and the seeds rattle when shaken in the pods.

Beans may be cut with the self-binder, the manual reaper, or a "fagging" hook, and tied into sheaves.

The sheaves are stooked with about three pairs together, and left till sufficiently dry to be carted into a stack. It is important to see that the sheaves are dry before stacking, otherwise the beans will mould, with consequent blackening of the seeds. The stacks should be well thatched and not made too big.

It is usual to leave beans in the stack to condition before threshing, and, within reason, the longer they are left the better for food purposes.

Threshing is now done with the ordinary threshing-machine, when the "drum" is set sufficiently wide to prevent splitting the beans, and riddles with larger-sized holes than are used for cereals have to be inserted.

The grain may be stored in a dry granary and left till sold or used for feeding purposes.

Yield.

The yield of grain may be anything from 25 to 40 bus. per acre or even more, and the bushel weight is usually from 63 to 66 lb., although 70 lb. per bushel may be obtained in some cases.

The straw in a good crop may be from 25 to 40 cwt. per acre. Roughly speaking, the straw in an average crop will weigh about twice that of the grain.

COST OF GROWING BEANS

The cost of growing beans is a very variable figure, as it varies with the class of land and even on the same class of land on two adjacent farms. It is affected by the cost of horse and manual labour, the particular rotation adopted, the cost of seed and implements, as well as by the rent, rates,

&c., of the land. It should include threshing and marketing of the beans if they are not used on the farm. All these charges are very real to the farmer, and have to be balanced against the returns in deciding whether or not it is advisable to continue growing this crop.

The returns are, on the other hand, even more variable than the costs of growing. When there is a severe attack of the bean aphis, bean rust, chocolate spot, &c., the returns are very disappointing, but in favourable seasons, and in the absence of such diseases and pests, good returns are secured.

In practice one cannot generalize either on a good or on a bad crop, but should take as fair an average as possible; hence the following production costs are given for typical bean land, i.e. clay loam to clay, and for average conditions.

Most of the items given below involve horse and manual labour, which in pre-war times were often taken at 2*s*. 6*d*. per day for each man and horse respectively employed. At the time of writing (1921), however, it is necessary to increase these figures considerably, and in these calculations horse labour is charged at 6*s*. per horse per day and manual labour at 7*s*. 6*d*. per day. Further, it is assumed that the grain is marketed.

ESTIMATED COST OF GROWING WINTER BEANS PER ACRE

1. *On Heavy Land after a Cereal Crop.*

	£	*s.*	*d.*
Cultivating and harrowing	0	12	6
Collecting and burning weeds	0	12	0
Preparing, carting, and spreading farmyard manure	1	13	3
Ploughing	1	13	0
Harrowing	0	4	0
Artificial manure, 6 cwt. basic slag per acre, amount chargeable against bean crop	0	18	0
Drilling	0	7	0
Seed beans, say	2	0	0
Harrowing and water furrowing	0	7	4
Horse hoeing (spring)	0	10	6
Hand weeding	0	12	0
Opening out, cutting with machine, tying up, stooking, &c.	1	7	6
Loading, carting, stacking	1	4	0
Threshing, including hire of machinery, necessary horse labour	1	1	0
Marketing	0	10	0
Rent, rates, &c.	2	5	0
	15	17	1

2. *Winter Beans after Roots* (land free from weeds).—The cost of growing beans after roots would be the same as after a cereal crop, after deducting the first three items, viz. £15, 17*s*. 1*d*. less £2, 17*s*. 9*d*. = £12, 19*s*. 4*d*. per acre.

3. *Spring Beans after Cereal Crop or Roots.*—As long as the land is fairly clean, the cost of growing spring beans would be approximately the same as in (2) above.

See also Article Cost of Production of Grain Crops, p. 303.

BENEFITS FROM GROWING BEANS

The two chief benefits from growing beans are:

1. They are leguminous plants, and enrich the soil through their power of fixing the nitrogen from the air in the soil by means of bacteria in the root tubercles, as explained above.
2. The grain supplies one of the richest nitrogenous foods that is grown on the farm. On this account beans have a special value for improving and giving better balanced rations of home-grown and other foods that are fed to farm live stock.

The grain contains approximately 22 to 25 per cent albuminoids, 1½ per cent oil, 50 per cent carbohydrates, and 9 per cent fibre. From this it will be seen that beans are not a very well balanced food, inasmuch as they are poor in oil; but in some cases this may be an advantage, especially when they are fed to horses doing fast work. Generally speaking, they should be fed in conjunction with other foods, e.g. cereal grains, so as to make a better balanced ration.

For horses doing hard work beans have a special value, seeing they are *par excellence* muscle formers; and horses receiving beans even as a minor part of the grain ration—or, in extreme cases when beans are cheap and plentiful, as the major part of the grain ration—have wonderful staying power. Although they may not carry much flesh they will develop short, sleek coats and be able to do the work quickly and easily.

When beans form a large proportion of the grain ration it must be borne in mind that they tend to produce flatulence or colic, and may prove to be of a rather astringent nature; hence it is generally necessary to feed at the same time, as occasion demands, some food of a laxative nature, such as roots or linseed oil.

Bean meal forms a valuable constituent of a ration for dairy cows, and it is effective in raising the albuminoid ratio of the concentrated food given. At the same time it does not give any undesirable flavour to the milk, and the butter made from the milk is firm and of good quality.

For bacon production it has the advantage of being poor in oil, and a low percentage of oil in the meal mixture is desirable in a pig meal where prime quality bacon is the object. For this purpose one part of bean meal to four parts of cereal meals (barley, maize, ground oats) would be a useful proportion.

Bean straw is comparatively rich in albuminoids, and horses sometimes prefer it to hay. When of good quality, the work horses may have their racks filled with it each evening, and any bean straw which is not eaten will make excellent litter.

Bean straw is not suitable for cattle unless it is first chaffed, and fed with meals and pulped roots.

In some districts where the grain is required for feeding on the farm, a mixture of beans, oats, and peas may be grown instead of beans only. A suitable seed mixture per acre would be 2 bus. beans, 2 bus. oats, and ½ bus. common grey field peas. The seed may be drilled in February or March. In some cases the oats are drilled a fortnight later than the beans and peas, and a late ripening variety of oat is used, so as to ensure the different crops ripening at about the same time.

Beans may also be used in a mixture similar to the above for cutting green and making into silage.

FOREIGN BEANS OF AGRICULTURAL IMPORTANCE

The following foreign beans are used in this country for feeding purposes:

Soya Bean (*Glycine hispida*).—This is a leguminous plant which is largely grown in Manchuria, northern China, Japan, America, &c., and produces seeds in pods about the size of an ordinary pea. The seeds are generally of a pale yellow colour, containing about 36 per cent albuminoids and 16 to 20 per cent of oil. In view of their richness in oil it is usual to express a considerable portion of the oil, and the residue so obtained supplies a valuable feeding cake called soya bean cake, with an average composition of 43 per cent albuminoids, 6 per cent oil, 28 per cent carbohydrates, and 4 per cent fibre.

Indian Pea or Gram (*Vigna catjong*).—The grain is about the same size as a field pea, dull greyish in colour, and of a peculiarly angular shape. Its average composition is albuminoids 18 per cent, oil 4 per cent, carbohydrates 58 per cent, and on this account it is becoming increasingly popular for blending with other foods which are low in nutrient constituents.

Java Beans (*Phaseolus lunatus*).—These beans should be fed to stock with considerable caution, inasmuch as prussic acid may be generated when they become mixed with the digestive juices. Prussic acid is a deadly poison which may have fatal effects on the animals consuming these beans.

Locust Beans (*Ceratonia siliqua*).—The valuable part of the locust bean or carob tree for feeding purposes is the thick pod, which has a sweet taste and agreeable smell. It grows in the Mediterranean district, where

the pods are shaken off the tree while still unripe and are then dried in the sun. This ripens the pod and causes it to darken in colour. The seeds are very hard; hence it is usual to extract them and retain the pods for stock-feeding purposes.

The composition of the locust bean is about 6 per cent albuminoids, $1\frac{1}{2}$ per cent oil, 70 per cent carbohydrates, and 6 per cent fibre. The sweet taste and agreeable smell give these beans a distinct value as a condimental food.

PRODUCTS OF BEANS

BY CHARLES CROWTHER, M.A., PH.D.

Beans are grown both as field and garden crops in numerous varieties, chiefly for the seed, which is a valued food for both man and beast. On the farm the chief varieties of the common bean (*Vicia faba* or *Faba vulgaris*) grown are: the English horse bean or Tick bean, the Scotch horse bean, the winter field bean, and the Heligoland bean. Beans of all these varieties form excellent food for live stock, whilst the haulm or straw despite its coarseness is, if well harvested, a very serviceable fodder for the older cattle.

The chemical composition of beans usually approximates to the following figures:

	Per Cent.
Moisture	$14\frac{1}{2}$
Albuminoids	25
Oil	$1\frac{1}{2}$
Soluble carbohydrates	48
Crude fibre	7
Ash	4
	100
Starch equivalent (production)	66

It will be seen from these figures that beans are fully twice as rich in nitrogenous ingredients (albuminoids or flesh formers) as the cereal grains, and they rank indeed, along with peas, as the most nitrogenous feeding stuffs commonly grown on the farms of the United Kingdom. In addition they supply considerable quantities of soluble carbohydrates, of which about three-fourths consists of starch. The various ingredients are highly digestible (85 to 95 per cent), and taken together constitute a feeding stuff little, if at all, inferior in nutritive value to the best oil-cakes.

The mineral matters or "ash", though small in quantity, are of considerable importance, being particularly rich in phosphoric acid (39 per cent) and potash (41 per cent), though poor in lime (5 per cent). This richness in nitrogen, phosphoric acid, and potash confers a high value upon the manurial residues arising from the consumption of beans. According to Hall and Voelcker's tables, as revised in 1913, the compensation for the unexhausted value of each ton of bean meal consumed is:

	For the Last Year.	Second Year.
Food consumed in yards	36*s*. 4*d*.	18*s*. 2*d*.
" " on the land	48*s*. 4*d*.	18*s*. 2*d*.

If assessed upon the same basis at the present time (1922), but in accordance with current costs of manures, these compensation values would be increased by 15 per cent.

In addition to home-grown beans, beans are imported from other countries, often unfortunately in very dirty condition. Many of these are varieties of the common horse bean, and if clean are quite good foods. Others, though similar in composition, belong to a different type (Phaseolus), and require a certain degree of caution in their use, since some consignments have proved to be distinctly poisonous. Such are the beans described as Java beans, Rangoon beans, &c., varieties of *Phaseolus lunatus*, which contain an ingredient that, in contact with water, gives rise to a certain amount of prussic acid. Cases of actual poisoning are not very frequent, but, in view of this risk, it is safest to regard foreign beans and bean meal with suspicion, and to test their wholesomeness on the less valuable stock before putting them into general use.

Beans are usually fed either in split form or ground to meal. Bean meal is a very popular food for many classes of stock, but, in view of what has been said as to the defective character as to cleanliness and wholesomeness of many imported beans, the prudent farmer will be cautious in the purchase of prepared meal, and will be generally well advised to purchase the whole beans rather than the meal.

Beans (and bean meal) are found by experience to be a "strong" food of a somewhat "heating" character. They are hence best suited for stock of mature age, and in any case are best given in admixture with other foods. If this latter precaution is sufficiently observed, beans can be fed to almost any class of stock. Thus bean meal, in admixture with roughly an equal amount of linseed cake, has given excellent results in the rearing of calves, in cases where little milk is available for the purpose. Beans are chiefly used in the feeding of dairy cows and hard-worked horses. For the former the beans are usually fed as meal at the rate of 6 lb. or more per head per day in the case of cows in full milk.

In the case of horses the beans are usually given in the split form in admixture with three or four times their weight of oats.

Bean meal is also reputed to be a good food for mature sheep, especially rams, up to ½ lb. per head per day being given. It is also a useful supplement to potatoes in pig feeding, but needs to be introduced gradually.

Beans and bean meal are commonly fed dry, but, where it is desired to feed large quantities, it is best to allow them to soak in water for some time until partly swollen. Soft water is best for the purpose, since hard water tends to form indigestible lime compounds with the albuminoids, especially if heated with the beans.

Bean Straw.

The value as fodder of the straw or haulm of the bean plant varies greatly according to the degree of ripeness at the time of cutting, and the amount of weathering it receives during harvest and in the stook. It is always rather coarse in texture, and is very liable to mould if not thoroughly dried, but if cut before the stem darkens and the eye of the seed turns black, and then well harvested, it gives a fodder not much inferior to a good meadow hay, the most nutritious parts being the upper stems, including the pods. If, on the contrary, the crop be dead ripe when cut, it is doubtful whether the straw is of much value as fodder.

The general character of the composition of bean straw and parts thereof is indicated by the following averages, based mainly upon analyses of home-grown crops (Wood and Halnan):

	Bean Straw (including Pods).	Bean Stems and Leaves.	Bean Cavings.	Bean Pods.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Moisture	14·0	14·0	14·0	14·0
Albuminoids	4·5	4·4	7·6	7·7
Oil	0·8	0·8	1·1	0·9
Soluble carbohydrates, &c.	33·0	35·0	34·8	42·6
Crude fibre	43·1	42·4	36·2	28·5
Ash..	4·6	3·4	6·3	6·3
	100·0	100·0	100·0	100·0

"Starch equivalent" for maintenance, 44.
" " " production, 19.

These figures indicate that good bean straw is more nitrogenous than, but otherwise not unlike, cereal straw. Taken as a whole, the constituent parts are rather more than one-half digestible (55 to 60 per cent), and

the feeding value of the digestible portion may be reckoned about equal to that of good oat straw.

It requires greater caution in feeding, however, than cereal straw owing to a tendency to produce flatulence, especially if damp or mouldy It is, moreover, more susceptible to damage by moulds and fungi, and if badly affected should if fed at all be first chaffed and thoroughly steamed. The safer plan is to use inferior bean straw only as litter, although for this purpose it is less useful than cereal straw, owing to its lower absorptive power for liquids and the slowness with which it rots down into manure.

The ash of bean straw that has been harvested under dry conditions is usually rich in potash (30 to 35 per cent) and lime (20 to 25 per cent), but does not as a rule contain much phosphoric acid (5 to 8 per cent).

THE PEA CROP

By JOHN PORTER, B.Sc.

Peas have been cultivated in field and garden from time immemorial, and the name is generally associated in Great Britain with two genera, viz. Pisum and Lathyrus. The former includes the field and garden peas, and the latter various plants grown more particularly for their flowers, such as the Sweet Pea (*L. odoratus*) and the Everlasting Pea (*L. latifolius*).

The common field pea (*Pisum arvense*) is said to be a native of central and southern Italy, and apparently from this source has spread to all the temperate parts of the world. Its beautiful purple flowers are very conspicuous, and have practically the same colours as the prototype; but in the case of the garden pea (*P. sativum*) the flowers are white, and a prototype with white flowers does not appear to have been discovered; hence it is assumed that the garden pea may possibly have been derived from the common field pea.

De Candolle points out that the word *pison*, or its equivalent, occurs in both the Albanian and the Latin tongues, from which he concludes that the pea was known to the Aryans, and may possibly have been brought by them into Greece and Italy.

Peas have been found in Swiss lake dwellings of the Bronze Age, which is additional evidence of their cultivation dating from very early times.

ACREAGE UNDER PEAS

In Great Britain peas were much more widely grown as a field crop previous to the introduction of clover and roots into the rotation than has subsequently been the case. This was largely due to the fact that peas and beans were the chief crops grown between two cereal crops at that time.

The following figures show how the acreage under peas dropped rapidly after the seventies of last century:

Year.	England.	Scotland.	Wales.	Great Britain.
	Acres.	Acres.	Acres.	Acres.
1868 ..	291,560	2001	2673	296,234
1869 ..	390,950	2067	3160	396,177
1871 ..	382,104	2909	4534	389,547
1881 ..	213,247	1557	1984	216,788
1901 ..	152,185	1349	1596	155,130
1912 ..	200,362	1184	773	202,319
1916 ..	112,068	591	615	113,274
1918 ..	149,230	417	874	150,521

The returns given for Scotland in 1912 include 571 ac. of peas picked or cut green and 447 ac. in 1916.

The area under peas in Ireland appears to be very small indeed.

There are only three counties in Great Britain which grow over 20,000 ac. of peas per annum, and these are the famous seed-growing counties in England, viz. Essex, Suffolk, and Lincolnshire. This is probably due to the fact that these counties, generally speaking, have a comparatively low rainfall, which facilitates the harvesting of this rather " delicate " crop.

The next highest acreage of peas in a county is less than 9000 ac. per annum, and for comparative purposes those counties which grow over 3500 ac. of peas are included in the following table.

In addition, the proportion of arable land under peas in each county has been worked out by the writer, in order to emphasize the fact that the proportion of arable land under peas is very small indeed.

As regards Suffolk, 15,039 ac. of the area under peas are in East Suffolk. Similarly in Lincolnshire, 9596 ac. are in the Lindsey division, and the remainder are equally divided between Kesteven and Holland. In Yorkshire, the East and West Ridings have about the same acreage, viz. 3527 ac. and 3743 ac. respectively, while North Riding has only 1427 ac. under peas. In Cambridgeshire the area under peas

Table showing Acreage of Peas grown in Principal Pea-growing Counties

(Taken from the Ministry of Agriculture's special compilation of the crops grown in each county for the year 1915)

County.	Area under Peas.	Total Arable Land.	Percentage of Arable Land under Peas.
	Acres.	Acres.	
Essex	22,151	507,034	4·3
Suffolk	21,524	564,176	3·8
Lincoln	20,202	994,111	2·0
York	8,697	1,104,905	0·8
Kent	8,424	291,941	2·9
Norfolk	7,894	780,687	1·0
Worcester ..	4,668	121,255	3·8
Cambridge ..	4,408	375,284	1·2
Nottingham ..	3,510	216,531	1·6

is about equally divided between the Isle of Ely (2319 ac.) and the rest of the county (2089 ac.).

SOILS FOR PEAS

Peas can be grown successfully on a wider range of soils than beans, but, generally speaking, prefer light land. The typical soil is a light calcareous loam, but they grow well on sandy and gravelly soils if lime is present.

Good barley land is usually good pea land, while good wheat land is as a rule good bean land. At the same time large crops of peas may be obtained in suitable seasons even from heavy soils.

CHARACTERS OF THE PEA PLANT

The pea belongs to the natural order Leguminosæ, on account of its fruit being a legume. Other characters of the pea plant are as follows:

The seed resembles that of the bean to some extent, but, generally speaking, is smaller and rounder. On germination the seed-leaves or cotyledons remain permanently below ground, instead of appearing above the surface soil as in the case of beans.

The root is a tap root, which gives off secondary roots having nodules. These nodules are the medium through which the nitrogen from the soil air is secured and passed on to the plant in a form in which it can

be utilized by it. In consequence, peas are less dependent on supplies of nitrogen from artificial or other manures than are those plants which do not form nodules.

The stem or haulm of peas is round in section and too weak to support the plant in an erect position. It is therefore unlike the stem of the field bean.

The leaves are compound, consisting of two or three pairs of leaflets, and on each side of the stalk of the leaf, where it joins the stem, there are two large leaf-like stipules. The extreme end of the leaves develops one or more pairs of tendrils, which are sensitive to contact and have the power of twining round or clinging to any small support which they touch, and it is in this way that the plant is prevented from collapsing under the weight of its own haulm.

The flowers grow from the axils of the leaves and produce pods or legumes as fruits. The pods of peas differ from those of beans by the inside of the pods of the former being free from downy hairs, which are generally present in the pods of the latter.

VARIETIES OF PEAS

The peas which are grown for their seeds as an article of food, either for farm live stock or for human beings, may be divided conveniently into two groups, viz. (1) Common Field Peas, (2) Garden Peas.

" Picking " peas is a term which is often applied to garden peas grown on a field scale, picked green, and sold for human consumption as a vegetable. It is to the cultivation of peas on a " field " scale that the present article applies.

The Field Pea (*Pisum arvense*).—This is a hardier type than the garden pea. Its flowers are of a very conspicuous colour with the " standard " or big petal lavender and the " wings " or side petals of a deep rosy purple. The ripened seeds may be dun coloured, greyish brown, or speckled brown and grey. The pods and seeds are smaller than those of garden peas.

Each leaf consists of one or two pairs of leaflets. The chief varieties in cultivation are: (1) Common Grey pea, (2) Partridge pea, (3) Grey Maple pea, (4) Grey Warwick pea, (5) Dun or Dutch pea, (6) Winter pea.

Common Grey Pea.—This is a late variety with dun-grey or brownish-grey seeds. It is widely grown, and is a good cropper; its pods have often as many as eight peas inside.

Partridge Pea.—An early variety that can be grown in late districts. The seeds are medium sized, and of a speckled brown-grey colour. The length of the haulm may be 3 ft. 6 in. to 4 ft. and the leaves made up of fairly big leaflets.

Grey Maple Pea.—Similar to Partridge, but the seeds are larger, and the variety is more suitable for richer soils and warmer districts.

Grey Warwick Pea.—An early variety, a quick grower, can be successfully grown in late districts on suitable soils. Being early, the yield is not so heavy as with later varieties. Haulm about 3 ft. long; pods have three to four seeds as a rule. The seeds are of a speckled brown and grey colour.

Dun or Dutch Pea.—A tall-growing variety, suitable for light soils in early districts. It has fairly large, wrinkled seeds of a dun colour, hence the name.

Winter Pea.—A more hardy variety, which can be sown in the autumn for early harvesting the following year. In mild winters it does well, but in severe ones is apt to be killed off by frost.

The Garden Pea (*P. sativum*).—Varieties of the garden pea are less hardy than field peas. They have "white" flowers. The seeds are of uniform colour and may be pale yellow, green, or white. They are usually larger than field peas. The varieties with dwarf to medium-length haulm are often grown on a field scale for picking green.

Pisum sativum: Dwarf variety

Pisum sativum: Tall variety

Garden peas are generally divided into two groups according as their ripened seeds are wrinkled or round. The former are often called Marrowfats or marrow peas.

On account of the large number of varieties grown, it is scarcely possible to do more than mention a few of the early, mid-season, and main-crop varieties. The approximate height of the variety is placed in brackets behind each name.

Early varieties.

(*a*) *Round seeds*: Early Eclipse (2½ ft.), Pilot (3 ft.), Primo (3 ft.), and British Lion (3 ft.).

(*b*) *Wrinkled seeds*: Little Marvel (2 ft.), Gradus (3 ft.), and Thos. Laxton (3 ft.).

Mid-season and main-crop varieties.

(*a*) *Round seeds*: Fill-basket (2½ ft.), Essex Star (3 ft.), and President (3 ft.).

(*b*) *Wrinkled seeds*: Daisy (1½ ft.), Dwarf Defiance (2 ft.), Rent-payer (2½ ft.), Senator (2½ ft.), and Union Jack (3 ft.).

PLACE IN ROTATION

Peas may come between two cereal crops, or after temporary pasture. Being a leguminous crop they are also taken in place of clover in some rotations, while on chalky soils they are often taken after roots.

During the Great War, when the Government "ploughing up" policy was being enforced, it was demonstrated again and again that peas were one of the safest crops to grow on newly-ploughed-up old pasture-land.

Time of sowing.

The winter variety is generally sown in October, but the crop is easily injured by frost and is risky to grow. The other varieties of field peas are sown in the end of February or early in March.

When "picking" peas are being grown for seed, they may be sown in April or early May, so as to be ready for harvesting in the late summer.

PREPARATION OF SOIL, MANURING, ETC.

Where peas follow a cereal crop, the stubble should be harrowed immediately after harvest to germinate weed seeds, and every effort should be made to get the land as clean as possible during the autumn. Give the land about 10 to 15 tons dung per acre and plough in. Leave land to weather through the winter. Cultivate in late February or early March and harrow to get a satisfactory tilth. Apply, say, 6 cwt. slag and 2 cwt. kainit per acre before drilling seed.

Field peas are usually sown with an ordinary corn drill at the rate of $2\frac{1}{2}$ to 3 bus. per acre, the width between the rows being about 14 in.; but in the case of picking peas, these are sown with a special pea drill, which sows 3 or 4 rows at a time, these being 14 to 18 in. apart, so as to admit of subsequent horse hoeing. The amount of seed required is from 3 to 4 bus. per acre.

As soon as peas get sufficiently well through the ground, horse hoeing should commence, and be repeated as often as is necessary till the peas close up the drills, otherwise the crop soon gets very weedy. With "picking" peas it is generally necessary to give them an early dressing of some nitrogenous manure such as nitrate of soda or sulphate of ammonia in order to push on the crop. At the same time it gives greenness and succulence to the pods and seeds.

PICKING OR HARVESTING

The earlier varieties of peas should be ready to pick green in July. It is then necessary to secure a small army of pickers. The cost of picking by hand varies considerably with the crop and the size of pods, but 1*s.* to 2*s.* per pot or bag of 40 lb. of peas (i.e. in the pods) was being paid in Worcestershire during 1920. The earlier varieties and light crops generally approximate to the higher figure, while the main crops and big crops generally approximate to the lower figure.

The yield may be anything up to 200 pots or bags of 40 lb. each per acre; occasionally more than 300 pots may be obtained, but 150 to 200 pots may be taken as a good average. Generally speaking, the early varieties yield a smaller crop than the mid-season or main crop varieties.

In the case of "picking" peas intended for seed, these are cut when ripe with a hook or scythe and put into small heaps to dry. The peas may be turned very carefully a few times if necessary, and when sufficiently dry carted into a stack or loft. Careful handling is essential during harvesting, otherwise much seed will be lost.

With common field peas the earlier varieties are generally ready for cutting by the middle of July. They should be cut when the lower pods and straw turn a brown colour. The cutting is often done with a side-delivery reaper, and in this way the peas will be left more or less in small heaps, and when the haulm is quite dry, they may be carted into stacks. The cutting may also be done with a special fagging hook and the crop tied into bundles or wads. These are not stooked but left on the ground, and turned over occasionally to dry. The crop requires to be very carefully handled, especially in wet and showery weather, otherwise much seed will be left on the ground.

Yield per Acre.

The yield varies considerably, especially in the case of garden peas which are grown for seed. These are a very speculative crop to grow, and in unfavourable seasons the crop may be very poor indeed. In good seasons, however, the yield may be anything from 20 to 40 bus. or even more, an average figure being about 25 bus. per acre. Common field peas would average about 28 bus. per acre. The bushel weight is 63 to 65 lb., although in small round peas, such as the common field pea, it might rise as high as 70 lb. per bushel.

A fairly good crop would yield about 1¼ tons per acre of haulm or pea straw.

COST OF GROWING

In order to arrive at the cost of growing peas it will be necessary to divide peas into three groups, viz. (1) common field peas, (2) garden peas grown for seed, (3) garden peas sold in the green state (picking peas).

Common Field Peas.—In this case the cost approximates very closely to that of spring beans grown after a cereal crop. The cost in this case was given as £13, 1*s*. 4*d*. per acre (see under Beans); but as the seed is more expensive, and as the harvesting requires considerable care, the extra cost would bring the total up to about £16 per acre.

Garden Peas cut for Seed.—The chief differences between the cost of growing garden peas on a field scale and the common field pea are: (1) the cost of the seed is very much greater, depending on the variety grown, and (2) the cutting is generally done by hand, as with these expensive seeds greater care has to be taken. These two items would probably add another £4 per acre on to the cost of growing common field peas, making a total of approximately £20 per acre.

Garden Peas picked Green ("Picking" Peas).—Picking peas have to be grown on more intensive lines altogether than in the two former cases, so as to get the early market, and at the same time place them on the market in an attractive manner, so far as colour, well-grown and well-filled pods are concerned. This means that nitrogenous manures have to be given to stimulate growth, and extra horse and hand cultivations have to be given. The picking and marketing costs are also very heavy; hence it is necessary to give a separate detailed statement of the cost of growing picking peas. In the following calculation it is assumed that the peas follow a cereal crop or roots in the rotation. See under Beans as to daily costs of horse and manual labour used in the following calculations.

After roots which have been dunged this item may be reduced; but with roots "sheeped" off, the pea crop would have to be debited with

Approximate Cost per Acre of Growing "Picking" Peas (Season 1921)

	£	s.	d.
Autumn cultivations and ploughing in dung	1	15	0
Preparing, carting, and spreading dung	1	13	3
Cultivating and harrowing (spring)	1	17	0
Basic slag (6 cwt. per acre) chargeable against pea crop	0	18	0
Seed—varies with variety, say	9	0	0
Drilling of seed	0	7	0
Harrowing	0	4	0
Horse and hand hoeing	1	0	0
Top-dressing with nitrogenous manures	2	0	0
Picking—say 200 pots at 1*s.* 6*d.* per pot or bag	15	0	0
Carting haulm off	0	10	0
Cartage to station, railway charges to market, commission, &c.	5	0	0
Rent, rates, &c.	4	0	0
Total cost per acre	43	4	3

the major part of the value of the sheep manure. Where peas are carted direct to market the cost on this item may be decreased.

It will be noticed that the cost of growing picking peas at the time of writing (1921) is very heavy, and when valuable varieties are used, and the crop well grown, the cost is somewhere near £40 per acre.

Although these heavy expenses are incurred in anticipation of good results accruing, there is a considerable risk as to what the resulting crop will be, as well as to the price that will be obtained. With a good crop and big prices for the peas the results are highly satisfactory; but disappointing crops and low market prices are not uncommon. Hence farmers who have not grown picking peas before, should grow a comparatively small area at first, and increase the acreage as their experience widens and the results obtained have proved that the soil and returns are satisfactory.

UTILIZATION OF PRODUCE

Peas of the garden varieties are extensively used for human food, both in the form of soup and, after boiling or steaming, as a vegetable. They may also be eaten uncooked in the green succulent state.

The grain of the common field pea is a favourite food for horses doing fast work, chiefly due to its being rich in albuminoids (22½ per cent) and low in oil (1½ per cent). The albuminoids form muscle and give great staying power to horses. On account of peas being low in oil they are not of a heating nature. When fed to farm live stock, peas should generally be blended with meals or offals from cereal grains.

Peas, when used in conjunction with cereal grains, form an excellent food for feeding sheep, for calves, and for milking cows. For pig feeding there is no doubt that the finest quality of bacon can be produced with a blend of pea and barley meals, and even when separated or skim milk is not available the addition of pea meal enables one to use water in the place of skim milk and obtain satisfactory results.

The straw when harvested in good condition makes an excellent fodder and is much relished by stock.

PRODUCTS OF THE PEA

By CHARLES CROWTHER, M.A., Ph.D.

The pea is grown both as a field and garden crop in very numerous varieties. It is grown chiefly for the seed, but on the farm the straw or haulm also forms a useful adjunct to fodder supplies. Two species of peas are usually recognized, viz. the field pea (*Pisum arvense*) and the garden pea (*Pisum sativum*), the former being chiefly grown and used for feeding stock, whilst the latter mainly serve for human consumption. We are concerned here only with the field pea.

Pea Seed.

The composition of individual samples is subject to great variations, but the following may be taken as typical:

	Composition. Per Cent.	Digestibility (Cattle or Sheep). Per Cent.
Moisture	14	—
Albuminoids	22½	86
Oil	1½	65
Soluble carbohydrates, &c.	53½	93
Crude fibre	5½	70
Mineral matters (ash)	3	—
	100	
Starch equivalent (production)	72	

It will be noted that peas are relatively rich both in albuminoids and in carbohydrates, and this constitutes their special merit for feeding purposes, no other home-grown grain food, except beans, being as

rich in albuminoids. The composition is considerably affected by the proportion of seed-coat (or shell) to kernel, the former having only a low feeding value. Other things being equal, small peas will have a larger proportion of shell than large peas and hence should, in general, be less nutritious, weight for weight, when grown under similar conditions.

The data given above for digestibility by cattle or sheep probably hold good fairly closely also for the case of swine and horses. They represent a rather higher degree of digestibility than is found for the cereal grains, but, on the other hand, the latter probably digest somewhat more rapidly.

Peas contain a higher proportion of mineral matter (ash) than most cereal grains, and this ash is characterized by its relative richness in phosphoric acid and potash. The average proportions of the chief ash ingredients are given by Wolff as follows:

	Per Cent.		Per Cent.
Potash	43·1	Magnesia	8·0
Lime	4·8	Phosphoric acid ..	35·9

These proportions of potash and phosphoric acid, along with, say, 3·6 per cent of nitrogen also present in the peas, will correspond to a manurial value (Hall and Voelcker, 1913) for compensation purposes of about 33*s*. per ton of peas consumed (under cover) during the closing year of tenancy (or about 35*s*. at current (1922) cost of manures).

Owing to their richness in digestible albuminoids, peas, like beans and other pulse seeds, form an excellent complement for feeding purposes to the cereal grains and other foods whose special characteristic is their richness in digestible carbohydrates. They are particularly useful for this reason in the rations of hard-worked horses, of milch cows, and growing stock of all kinds. There is a certain amount of risk, especially with horses, in feeding them freely in the dried condition, owing to their property of swelling up when moistened and the richness of their shells in astringent matter (tannins), whereby flatulence, colic, or more serious disorder may be caused in the alimentary tract. There is, moreover, further possibility of danger in the formation of intestinal concretions, owing to the richness of the ash in phosphates of potash and magnesia. When used in moderation, however, these properties may be made to serve useful ends, the astringent property rendering peas a useful corrective of unduly laxative food, whilst the richness of peas in phosphoric acid may be made very valuable for bone formation if the peas be suitably blended with foods whose ash is rich in lime.

Soft water is preferable to hard water for soaking peas, since the lime in the latter has a tendency to reduce the digestibility of the albu-

minoids. Where hard water only is available a small quantity of carbonate of soda (say 2 oz. per hundredweight of peas) should be added to remove the hardness.

To horses peas are commonly fed whole or roughly crushed (split peas), but to cattle and pigs in the form of meals. In the case of horses, peas should not as a rule form more than one-third of the total grain ration, or a lower proportion when the horse is only at light work. For fattening animals, especially pigs, pea meal is usually found to have a favourable influence upon the quality of the carcass. Pea meal is also held in good repute for milk production, but, if given in large amounts, may cause the butter to be unduly hard. Peas have also been used successfully in fattening geese and turkeys. By feeding peas soaked in buttermilk a fine, white, tender flesh is said to be produced.

Considerable quantities of peas are ground up for the production of pea meals, pea flours, &c., the finer qualities of which are used for human consumption in various forms. The pea shells removed in the milling process are often ground up and added to the coarser meals sold for agricultural purposes, which, moreover, are frequently adulterated with bean, maize, and other meals. It is preferable, therefore, to buy whole peas rather than meals if grinding plant is available. Imported peas are liable to contain angular pea-like seeds of *Lathyrus sativa*, which are said to be objectionable, especially for horses; so that samples containing these should be rejected.

Pea Straw or Haulm.

Pea straw when harvested in sound condition is the most nutritious of the straw fodders, being equally nitrogenous with bean straw and less coarse in texture. The pods and cavings form the most nutritious part of the haulm, as may be seen from the following averages based upon analyses made in the Cambridge laboratories:

	Pea Haulm.	Pea Cavings.
	Per Cent.	Per Cent.
Moisture	14·0	14·0
Albuminoids	9·2	11·7
Oil	1·6	2·4
Soluble carbohydrates, &c.	36·0	35·8
Crude fibre	33·4	28·0
Mineral matters (ash)	5·8	8·1
	100	100

The percentage digestibility of pea haulm (by ruminants) is given by Kellner as follows: albuminoids 60, oil 46, carbohydrates 64, and crude fibre 52. Assuming this degree of digestibility for each, the pea haulm

of composition shown above might be rated as perhaps 20 per cent inferior, and the cavings as similar in nutritive value to meadow hay of fair quality.

Like bean haulm, however, pea haulm is often not very palatable, it is very susceptible to fungoid attacks, and rather difficult to harvest in good condition. For these reasons, and owing to the usually limited supplies, it is commonly only fed in admixture with other fodders and roots. When chaffed or steamed it is usually relished by dairy cows and ewes.

THE MASHLUM CROP

By D. G. O'BRIEN
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The term " Mashlum ", peculiarly a Scottish one, is derived from the English " mash ", meaning " to mix ". It is probably identical in meaning with the old English word " meslin ", which is said to be derived from the old French word " mestillon ", meaning " mixed grain ". In its wider application, mashlum signifies any mixture containing beans along with peas, vetches, or oats. A mixture exclusively of beans and oats, however, is the generally accepted description of the crop in the south-west of Scotland.

Since the bean-oat mixture is principally harvested as a grain crop, while the others are used for forage purposes (see Volume IV), the former is alone referred to in this article.

Observations point to a greater productivity of these two crops when grown in admixture than when sown separately. This may be due to their different habits of growth and to the mutual protection afforded each other in the early stages of growth.

A further advantage of the practice is that the bean, on account of its thick stem, may serve as a " carrier " or support to the oat plant and thus lessen the risk which the oat plant runs of " lodging ". Moreover, weeds are kept down by the dense growth of the crop.

The adoption of the crop, on account of the nitrogen fixing properties of the bacteria in the bean root nodules, leads to economy in the use of nitrogenous manures, both for that and the succeeding crop.

Where Grown

Generally speaking, mashlum is grown to the greatest extent in those areas where beans do not form a crop in the recognized rotation. It is a common crop in the dairying districts in the south-west of Scotland, especially in Lanarkshire and Ayrshire. In these counties the bean

crop is considered to be rather speculative, but mashlum is a much more certain crop and seldom a failure.

Climate and Soil

The oat crop is much more hardy than the bean. The bean constituent of the mixture limits the crop to certain soils and to certain climates. For the successful growth of beans sown in the spring, the climate must be mild, since the bean plant in the seedling stage may be killed by hard frost. For this reason, in the south-west of Scotland, the sowing of the crop is postponed to the beginning of March, but the growth of the beans at an early stage depends more on securing a good tilth at seed time than upon the time of sowing.

A stiffish soil is most suitable for the crop, but such a soil must be well drained. Free drainage is imperative to success. Light sandy soils and peats are quite unsuitable; both are apt to be deficient in lime and potash, and frequently too in phosphate. A well drained clay soil, in good " heart ", recently limed, and at an elevation of not more than 400 ft. above sea level, is certainly ideal for the crop.

Place in the Rotation

With the exception of the clay-land rotation of North Ayrshire, no rotation defines mashlum as one of its common courses. In North Ayrshire, the rotation often practised is as follows: mashlum or oats, oats or mashlum, grass, grass, grass—a good rotation for the district, although it apparently breaks all the laws of good husbandry.

Mashlum elsewhere takes the place of the cereal crop. On the lighter types of soils, it is often grown after pasture, and is, in turn, followed by a root crop. On the heavier soils where root growing is not so extensively practised, it may be and generally is employed in that way, or it may be grown as an " aval " or second crop, in which case grass and clover seeds are sown out with the second or aval crop.

It is also grown, although to a lesser extent, after a root crop. Frequently where this is practised, comparatively few beans are sown, as the main object of including beans is to try to prevent lodging of the oats.

It is obvious that the mashlum crop is an adaptable crop capable of being grown in almost any place in the rotation.

Preliminary Cultivation

The land, whether lea or stubble, should be ploughed deeply in the late autumn or early winter. Nothing further requires to be done to the land until the sowing of the crop.

Manuring

The needs of the crop for manures are very similar to those of the oat crop. A little more potash and lime is required for mashlum than for oats. The nitrogen is best applied in the form of nitrate of soda or nitrate of lime. In the later stages of growth, the bean plant does not draw upon the store of nitrogen in the soil, but in the early stages of growth, especially if the weather be wet and cold, responds to artificial nitrogenous manures. The oat plant cannot function like the bean, and benefits from application of nitrogenous manures.

It is the custom of some growers to apply a dressing of 8 to 10 tons per acre of farmyard manure on the stubble before ploughing. This is especially done in those districts where few roots are grown, and where the mashlum crop can be regarded as the cleaning crop of the rotation. In addition to the dung, 2 cwt. of superphosphate and 1 cwt. potash manure salts may be applied per acre at the time of seeding.

When artificials only are used, the manures recommended may be increased by a half and nitrate of soda sown on the young braird at the rate of about ¾ cwt. per acre.

At first sight one might question the necessity of applying potash manures to beans, as a heavy soil is usually rich in potash. Application of potash manures to the crop, however, develops pod formation on the bean, and, like nitrate of soda, lengthens the period of growth of the oat crop, which is desirable, as the bean crop is rather late in ripening.

Seeding and Summer Treatment

The general practice is to broadcast the seeds separately, although there is no reason why the oats or the beans should not be drilled in. The customary rates of seeding per acre are about 14 st. of beans and 9 st. of oats, which represents an equal measure of each, namely 3 bus. Obviously, such a mixture may be considered perfectly arbitrary, and may be varied to suit the conditions under which it is grown. For instance, in a late wet spring when the bean constituent may possibly fail, the quantity of beans included may be materially reduced and the oat seeding proportionately increased. Similarly, the rate of seeding can be varied to suit different soil and other conditions. Variations in rate of seeding might run from 1¼ to 1¾ cwt. beans, along with 1 cwt. to ¾ cwt. oats.

In considering the time of sowing, it must be borne in mind that beans have normally a longer period of growth than oats. Consequently, the aim of the growth must be to try and arrange matters that the two components will reach maturity at or about the same time. This can be accomplished either by sowing the beans a few weeks earlier than the oats, or by employing a late ripening oat or an oat from a late district. It would be possible to attain the same end by utilizing an early ripening variety of beans.

The varieties of oats which are best suited for the purpose are Sandy, Tam Finlay, Blainslie, and Potato. These varieties, besides being later in ripening than the so-called grain-producing varieties, produce a bulky straw of good feeding value, and are decidedly surer by reason of their extra tillering power and hardiness.

The only varieties of beans which are sown in mashlum are the Carse and the Kilbride; both of these varieties are hardy and prolific. They are more or less alike in appearance, and it is extremely doubtful whether they are really distinct varieties.

The Granton bean, although not used for this purpose and certainly not so hardy, is earlier and might well be employed under favourable conditions. There is reason to believe that some of the varieties cultivated in England would be equally suitable on occasion. Experience on this, however, is negligible, as little experimental work has been carried out with the crop.

The method of sowing the seeds is very variable:

1. The seeds may be sown at the same time, though separately, and harrowed in.

2. The beans may be sown some two to three weeks before the oats, and only lightly harrowed in, in order to leave a seam or meat for the harrows when the oat seed is later broadcasted. When no seed bed is left, the oats may be drilled in on the top of the beans.

3. It is the custom in some districts to defer the ploughing of the stubble until seed time. The beans are then broadcasted and covered in by turning over a light or " skin " furrow. The oats are subsequently sown about a fortnight later and the land thoroughly harrowed.

Whatever the practice adopted, any crusting of the surface occurring before brairding should be broken by a light harrowing. This should only be done when the surface is dry and when the germinating beans are not too near the surface.

In all cases a light rolling completes the various tillage operations.

Generally the only treatment which the crop receives during summer consists in hand-pulling any thistles which may be present.

Measures for the eradication of runch or charlock are impossible, as any treatment which would exterminate these weeds would equally affect the bean plants.

Attacks of the bean aphis (Black Jack or the Collier) may, during dry seasons, cause considerable loss, but it is impracticable to apply any insecticide, either in a liquid or powdery form, to mitigate the trouble.

In some districts birds are especially severe on the crop. The bean plants in the crop enable the birds to get more easily at the oat heads. The beans afford a strong and firm perch for the birds.

Harvesting, Stacking, and Threshing

Mashlum is generally left to ripen for some time after the other grains are cut. As a rule, about a fortnight intervenes between the cutting of the last of the grain crop and the cutting of mashlum. The crop is ready for harvesting sometime in September; the date in any year depends mainly upon the season. At the time of cutting, the oats should be ripe, while the bean foliage will show signs of blackening and shrivelling, and the beans in the pods should be black at the hilum.

It is a mistake to defer cutting too long in the hope that the pods may be better filled and more mature. Although beans can withstand a considerable amount of weather, broken weather, such as generally sets in late in September or early in October, may materially reduce the value of the crop. Cutting, therefore, should not be unduly delayed, as the bean ripens considerably in the stook.

The cutting can be done with the greatest ease and satisfaction by the use of the self-binder. The reaping machine can likewise be employed, in which case the oat straw provides suitable straps or bands.

The sheaves are stooked in the usual way; fewer sheaves are generally placed in the stook than is customary with the oat crop in order to enable them to dry more quickly. Further, the sheaves, especially in poor windless harvest weather, may have to be turned in the stook.

In some of the later parts of the country the partially dried sheaves are put into " rickles ", " huts ", or " field-mows ". By adopting this practice the mashlum sheaves will keep for weeks in very bad weather, whereas, if left in the stook, the sheaves would be more or less destroyed. The oats would begin to sprout, the bean pods burst, the beans fall out or begin to germinate, and the quality of the produce would be greatly impaired.

It is advisable, especially in wet years, to build comparatively small stacks. The sheaves on stacking are not absolutely dead, and a certain amount of heat in the stack is always generated. In large stacks this heat might injure the quality of the crop. Care should also be taken to keep the centre of the stack well filled in or " hearted ", otherwise the stacks may draw water and fermentation set in.

The thatching is done in the usual way; wheat or rye straw may be used, although good long oat straw or even reeds may be employed.

As far as possible, threshing should be delayed to allow the beans to harden. If, however, mashlum be required for use shortly after harvest, a small quantity should be threshed at a time.

The oats may be separated from the beans at the time of threshing by passing the mixture over riddles of suitable mesh. As a rule, however, the bean and oat grains are not separated, the mixture being fed to stock.

Yield, Composition, and Utilization

A good crop would yield 18 cwt. or more of mixed grain and 25 to 30 cwt. of straw. So much depends upon the relative proportions of beans to oats that bushel weight is of little importance. A bushel weight of about 56 lb. ($\frac{1}{2}$ cwt.) would represent approximately an equal proportion by bulk of each in the mixture.

The following table gives the average percentage composition of digestible nutrients in the straw and grain of the components.

	Digestible Protein. Per Cent.	Digestible Fat. Per Cent.	Digestible Carbohydrates. Per Cent.	Nutritive Ratio.	Starch Equivalent.
Oat grain ..	7	4	48	1 : 7½	60
Bean grain	19	1¼	48	1 : 2¾	66
Oat straw ..	¾	½	38	1 : 50	17
Bean straw	1½	½	41	1 : 28	19

It will be seen that the grain and the straw of beans contain much more digestible protein than their counterparts in oats; also, that their nutritive ratios are narrower. The last column shows the relative feeding values.

In the ordinary course, concentrated foods have to be purchased to supplement the protein matter of the common home-grown foods. Bean meal is one of these, and for milk cows it serves the purpose excellently.

Mashlum, in addition to being used as a food for dairy cows, can be used for all classes of cattle, provided the mixture be ground into a fine enough condition. Improper grinding tends to cause impaction and constipation.

Mashlum grain either rolled or crushed is an excellent food for horses, and horses doing hard work, especially in winter, should have two or three pounds of beans in their daily ration.

Mashlum straw, if well secured, is palatable and may be fed to stock similarly to oat straw. The leaves and the pods of the bean straw have a food value almost equal to that of hay. The stems, however, are less digestible, and for this reason, when they are in larger proportion, it is sometimes advisable to chaff and steam the straw before use.

THE COST OF PRODUCTION OF GRAIN CROPS

By JAMES WYLLIE, B.Sc., N.D.A.(Hons.)

It is impossible within the scope of this article to discuss in any detail the general principles governing the determination of the cost of production of any farm product, or to explain the various records which are necessary in a complete system of farm cost accounting.

The first object in view will be to try to put the reader in a position to study cost statements intelligently, to criticize them relevantly, and to interpret them correctly. In point of fact, it is far more important that the farmer should realize clearly what is meant by saying that the cost of producing a quarter of oats is 40*s*. than that he should be asked or expected to take sides on what are after all more or less academic questions.

In the present state of costing terminology in this country, it is quite conceivable—indeed, highly probable—that on the same farm and in the same season one cost accountant might work out the average cost of oats to be 40*s*. per quarter, another 45*s*., and a third 50*s*. Each of these figures might be perfectly genuine and quite correct according to the basis upon which it had been obtained, but it is obvious that the value of farm costing must be considerably curtailed unless figures from different farms and from different accountants can be readily compared.

Further, it is necessary to point out that so-called "piece-meal" costing, by which is meant the costing of one article on a farm where several are produced, will be satisfactory only in a few cases. Thus during the Great War numerous costs were taken out separately for oats, for potatoes, for milk, &c., all of which were looked upon with suspicion, chiefly because their reliability could not be tested except on very general

grounds. Such costs may be, in fact, quite reliable, but they are severely handicapped by the lack of proof.

To be of maximum value, cost accounts must be built upon the sure bedrock of financial records of income and expenditure. The total profit for each farming year can be arrived at by means of simple financial records; cost accounts will neither increase nor decrease this profit, no matter on what principles they may be based; but the relative profits or losses shown by the different "departments" can be and are made to vary according to the procedure adopted at different stages in the costing process; so that the results from the cost accounts should always be studied in the light of the total profit from the whole farm.

To sum up, (1) the terms used in cost accounting must be clearly defined, (2) costs should be taken out for all the finished products on any given farm, and (3) they should be founded upon financial records.

These remarks appear necessary since this article deals only with the costs of production of grain crops, especially oats, wheat, and barley.

First, then, as to *definitions*. The writer has elsewhere[1] defined the cost of production of any farm crop to be "*such a figure as will represent the minimum net price at which a certain crop can be sold or otherwise realized if the farmer is to get* (a) *a fair return on his invested capital, and* (b) *a reasonable remuneration as manager of the business*". It thus includes (1) all labour costs of cultivation, seeding, manuring, &c.; (2) the cost of seed; (3) the cost of manures, lime, and other materials actually used by the crop; (4) a proportionate share of all overhead expenses—rent, rates, insurance, repairs and maintenance, fencing and ditching, &c.; (5) a charge for interest on the invested capital; and (6) a charge for the expenses of management. Definitions of each of these separate factors in cost of production will be given later with the help of a specific example.

If both interest and management charges are omitted, as will be found desirable for certain purposes, the resultant figure will represent the *net* or *bare cost* of production as contrasted with what may be called the *gross cost*.

Involved in the consideration of definitions is the question as to what particular information is most urgently required from the cost accounts. For example, in calculating the cost of horse labour a charge may be included for the cost of "stable time", and also for a proportion of the farm rent and rates to cover the use of the stable. This, of course, would result in some part of the man labour cost being "hidden" under

[1] *Journal of the Board of Agriculture and Fisheries*, July, 1917.

horse labour, while the direct charge to crops for rent and rates would also be less than it would otherwise have been.

Again, the total cost of a dressing of dung consists largely of man and horse labour costs; the same applies to lime and, to a less extent, all other material applications.

It is clear that the classification of the cost items will depend upon the object in view. If a main object be to show what percentage of the gross cost consists of man labour and horse labour respectively, then all man labour costs must be brought into one total, and so also for horse labour; but if, on the other hand, the object be to compare, say, the cost of ploughing by horses and by tractor, then the former would quite properly include the cost of stable time and a share of the farm rent and rates, while no comparison between the cost of manuring with dung and with artificials would be relevant unless the total costs were included in either case. Of course, proper cost records would contain all information necessary for any of the above objects, but the final cost statement must be kept within moderate dimensions, and hence it is necessary to decide what information it should give directly, leaving other information to be obtained by supplementary analysis.

In this connection it may be said that the compilation of *operation costs*, i.e. costs of ploughing, reaping, drilling, &c., involves an amount of detailed work, both on the farm and in the office, which rules this procedure out, except in very special cases, and if such a scheme were followed the cost sheet would be of a totally different character from that given below.

Further, the question arises as to the point at which the cost of any crop is to be determined. Is the cost of carting swedes from the field to the cattle turnip shed to be reckoned as part of the cost of turnips or charged direct to cattle? Is the cost of dressing 1920 oats for seed to be included in the cost of 1920 oats or charged direct to 1921 oats? It is clear that the cost of the turnip crop will vary according to whether it is consumed on the field where grown or carted some distance for consumption in the cattle sheds. Or again, should the cost of delivering oats, say, to the market be shown separately or analysed and included under man labour, horse labour, &c.?

In many cases it is advisable—for comparative purposes—to take out, first of all, costs on the farm (*farm costs* of production), but in calculating the percentage of, say, man labour it is generally total man labour and gross costs which should be the basis. Care must be taken to keep delivery costs separate in the records, so that they can be wholly charged to that part of the product actually marketed.

Hence, the bare statement that 30 per cent of the cost of growing oats consists of man labour is more or less meaningless, unless one knows (1) whether "cost" means gross cost or net cost, cost on the farm, or cost

delivered to the market; and (2) whether "man labour" means all the man labour expended upon the crop up to the time it is marketed or only the labour used in tillage, and apart from the applications of material and "stable time".

This aspect of the case bears particularly upon the interpretation and use of the cost accounts. What is the relative importance of a 10 per cent increase in rates, in wages, and in the price of manures? It would appear that even experienced farmers would be likely to go astray in answering such a question. For one thing, accurate cost accounts show that wages do not form such an overwhelming proportion of the cost of farm products as a certain school of public opinion would lead one to think; for another, it would appear that the relative total amounts of man labour required *per acre* by the different crops is a matter which requires very careful consideration. If it can be shown that man labour, manures, and rates constitute 30 per cent, 25 per cent, and 2 per cent respectively of the total cost of growing an oat crop, then the effect of a variation of 10 per cent in any one of them upon the gross cost can be readily gauged, while it is clear that a variation of 10 per cent in wages will have a much greater effect upon the cost of a crop which demands £10 per acre of man labour than upon one requiring only £3 per acre. These two questions should be considered together, and they can only be intelligently answered with the aid of properly kept cost records. In other words, the final cost sheet must show (*a*) the *cost per acre* of each factor in production, and (*b*) *the percentage* which each item of cost bears to the gross cost. From this point of view it will generally be advisable to include all man and horse labour under man labour and horse labour respectively, so that the figures given for seed, manure, &c., will refer only to the price of the materials.

It is now necessary to refer to the crucial problem in farm costing—the problem arising out of "joint costs". It is only a slight exaggeration to say that every farm product is the result of joint costs. Oats cannot be produced without straw; ware, seed, and brock potatoes are part of the same crop; hay is grown partly by direct but largely by indirect costs; the cleaning of the land for root crops benefits more or less all the crops in the rotation, and so on.

The immediate problem is to determine what part of the cost of growing a grain crop is to be allocated to the grain and what part to the straw. It has been suggested that the gross cost of the crop should be apportioned between grain and straw on the basis of the relative market values of the two products, but, since in most districts only nominal prices could be put upon straw, the basis is more imaginary than real.

Another proposal is to value the straw according to its feeding value compared with cakes and meals. As to this, it is hard to see why the

cost per ton of straw should depend in any way upon the market price of, say, linseed or cotton cake, and, in any case, no true comparison can be drawn between straw and cakes, since the former is complementary to the latter and not, generally speaking, a possible substitute for them.

There is, in fact, no alternative but to attach to straw what is considered to be its fair farm value, having regard to all the circumstances of each case. Straw which is tramped into dung may quite properly be priced at 10*s.* or 20*s.* per ton, whereas in the same season straw fed to dairy cows from a crop grown chiefly for the sake of the straw may with equal propriety be priced at 40*s.* to 60*s.* per ton. But in districts, as around large towns, where both grain and straw are readily saleable, the gross cost should be apportioned on the basis of the relative market values.

When it is borne in mind that straw is one of the connecting links between crops on the one hand and live stock on the other, the importance of this problem will be readily understood. It is clear that the relative profits or losses shown by crops as a whole and live stock as a whole depend partly upon the price put on straw, and it may be urged that the above method of "costing" straw lends itself readily to abuse. It is fairly certain, however, that the farmer who deliberately sets out to make a certain department pay well (on paper) at the expense of some other department will be the first, if not the only person to suffer.

The fact that arbitrary methods are unavoidable in farm costing is not, in itself, a proof that it is of no practical value. In every industry costing calls for the exercise of judgment, and is not by any means a purely mechanical process.

Turning for a moment to the interpretation of the results shown by the cost accounts, it is important to keep clearly in mind that the aim of the farmer is not so much the production of cheap oats, or cheap potatoes, or cheap hay as to make as large a total profit as possible from the farm as a whole. Low cost per unit, e.g. per quarter of oats or per ton of potatoes, low efficiency per farmer, low yield per acre, and low total farm profit may and do occur together, whereas a high cost per unit may accompany high efficiency, high yield per acre, and high total farm profit. Hence, the cost accounts must be viewed not as separate and watertight "compartments" but as parts of a whole.

In particular, the profits or losses from different rotations and systems of cropping rather than from individual crops should be the basis for judging the economy of the cropping department, although this does not mean that the costing of individual crops is useless.

Incidentally, passing reference may here be made to two common objections against the utility of farm costing. In the first place, it is only a misunderstanding of the real object of cost accounting on the

farm which leads to the criticism that it is useless because the farmer cannot control prices, and therefore that it is no advantage to him to know the cost. The fundamental and by far the most important object of farm costing is to enable the farmer to study the constituent costs of any article with a view to concentrating on economies which are likely to be most effective—having regard not only to costs and profits per unit of any article, but also total farm profits. And in the second place, it is said that farming conditions vary so much that true average costs for any product cannot be obtained without heavy expenditure. In reality, and so far as the individual farmer is concerned, average costs, even if they could be obtained, would be highly misleading.

On the other hand, the variation in costs under similar conditions of soil, climate, &c., can be made the basis for searching out the weak points on any farm. If oats cost 30*s*. per quarter on one farm and 40*s*. on a neighbouring farm of the same class, cost accounts and only cost accounts can show clearly why this is so. In short, relevant comparisons of costs are of very great value, whereas comparisons of costs obtaining under widely different conditions can, as a rule, do nothing but harm.

It is now proposed to bring the above discussion to a more or less definite focus by means of an actual example of cost finding. One grain crop is as good as another for this purpose, and we shall choose the oat crop on a typical oat-growing farm in the south of Scotland, season 1920. Exactly 100 acres were grown, and detailed records of cost were kept on a system devised by the writer. (See p. 309.)

The cost statement finally put into the farmer's hands showed the results in considerable detail—covering four foolscap pages—but for reasons of space, as well as to present the broad issues more clearly, only the summarized statement will be given here, on the opposite page.

First of all, a few remarks are necessary to put this example in its proper setting. On the farm in question the only grain crop grown is oats, and it forms the chief " money crop " in the rotation, which is normally oats, green crop, oats, hay, and two years grass. The season 1920 will be remembered for its high rainfall from July onwards. The date of commencing to cut was one of the latest on record, and although the harvest was protracted the whole crop was ultimately secured in good order. Taken all over, the crop was about the finest ever grown on the farm, and, in spite of the length of the straw and the nature of the season, there was comparatively little lodging. The whole crop was threshed with the travelling steam outfit, part of it being threshed and baled simultaneously.

The correct interpretation of the data given depends upon a knowledge of what each cost item really means, so that brief notes on each are now given.

FARM NO. 00. COST OF PRODUCTION OF 1920 OAT CROP—ON THE FARM[1]

Acreage: Lea, 60; Sow-out, 32; Aval, 8. Total, 100.

Varieties: Potato, 92 ac.; Record, 8 ac.

Details.		Total Costs. £ s. d.	Costs per acre. £ s. d.	Per Cent of Gross Cost.	Per Cent of Net Cost.
I. *Labour*: Manual		345 17 8	3 9 2	24·4	27·5
Horse		163 7 7	1 12 8	11·6	12·9
Total labour		509 5 3	5 1 10	36·0	40·4
II. *Seed*		191 0 0	1 18 3	13·5	15·2
III. *Manures and Cleaning Costs*		221 7 7	2 4 3	15·6	17·6
IV. *Rent and Rates*		110 0 0	1 2 0	7·7	8·7
V. *General Expenses:*					
Binder twine	£32 5 6				
Coir yarn	3 0 0				
Thatch	10 0 0				
Insurances	4 10 0				
Repairs and renewals	62 3 6				
Thresher hire	55 19 0				
Coals for thresher	14 5 0				
Establishment charges	45 10 0				
		227 13 0	2 5 6	16·1	18·1
Net farm cost		1259 5 10	12 11 10	88·9	100·0
VI. *Interest*—6% per annum		72 0 0	14 5	5·1	—
VII. *Management*		85 0 0	17 0	6·0	—
Gross farm cost		1416 5 10	14 3 3	100·0	—

TOTAL YIELD: (*a*) *Grain*: 5205 bus. (of 42 lb.), first and seconds.
(*b*) *Straw*: 175 tons.

YIELD PER ACRE: (*a*) *Grain*: 52 bus.
(*b*) *Straw*: 35 cwt.

	Per Quarter (336 lb.)	Per Bushel (42 lb.)	Per Ton.
Net farm cost	28*s.*	3*s.* 6*d.*	£9, 6*s.* 8*d.*
Gross farm cost	32*s.* 9*d.*	4*s.* 1*d*	£10, 18*s.* 6*d.*

Straw credited at £2 per ton or 70*s.* per acre.

Note: *Cost of marketing oats sold*, i.e. 3490 bus., was at the rate of 8*s.* per ton or about 2*d.* per bushel—*not* included in above statement.

[1] Acknowledgment is due to the Board of Agriculture for Scotland for the use of all cost data quoted in this article.

The **acreage** is as given on the Ordnance Survey maps, and no allowance has been made for hedgerows, &c.

Man labour includes the total farm cost of manual labour—men women, and boys; cash wages and perquisites of all kinds—required in the production of this crop. Even so, this must be qualified by saying that only workers actually employed and paid—in cash or in kind or by exchange—by the farmer are included. Thus the cost of the thresher includes manual labour in the shape of the driver and the feeder, who are not therefore paid directly by the farmer, while a part of the manure and lime applied was delivered at the farm by contract, so that the manual labour here involved has not been included. But a line must be drawn somewhere, and the method adopted keeps to the actual facts.

The cost of man labour for each worker was based upon the total cost, i.e. wages plus perquisites, divided by the number of days engaged on directly productive work. Hence due allowance has been made for broken time, holidays, sickness, "unproductive" work, &c. On this basis the cost per day for men workers varied from 9*s*. 6*d*. to 12*s*., the average being about 10*s*. 10*d*. The total man-labour cost here shown was equal to 31 per cent of the total man-labour bill for the year ended 28th May, 1921.

Similarly, **horse labour** includes all the horse labour actually expended on this crop, subject to qualification as above. As in the case of man labour, proper allowance was made for all idle time due to holidays, sickness, wet weather, horses not required, &c., by basing the cost per horse-day upon the total cost of horse labour divided by the number of productive days' work for the period. In calculating the cost of horse labour no charge was made for attendance—i.e. stable time—for stable rent, for interest, or for establishment outlays, but all other costs—shoeing, harness upkeep, veterinary expenses, &c.—were included. Home-grown oats and hay were charged at market prices less the cost of marketing, straw at farm value.

Altogether 428 horse-days were required at an average cost of 7*s*. 7½*d*. per day, of which 73 per cent consisted of the cost of foods. Although the percentage of days engaged on directly productive work for the period in question was only 43, the cost per horse-day is one of the lowest which has come under the writer's notice, as regards season 1920.

The **seed** consisted of 150 bus. purchased and 326 bus. once grown on the farm, the latter being charged at farm market price—7*s*. 6*d*. per bushel, compared with 8*s*. 6*d*. and 9*s*. 6*d*. per bushel actually paid for the purchased seed.

The chief difficulty in costing the oat crop lies in deciding what charge to make for **manures** and share of the general rotation cleaning costs, especially where about one-half the turnip crop is fed off by

sheep receiving a fair amount of trough-feeding. A fuller discussion of this problem will be more opportune under root crops (see Vol. II), where it has its origin, but in the meantime it may be said that a careful calculation was made, field by field, of the proportion of the manures and lime directly applied to the oat crop, which was used up by that crop, and also of the charge to be carried by oats for manures, lime, dung, and manurial residues from foods which were applied to previous crops. At the best the final figure can only be approximately correct. The figure given includes £46, 7*s*. 3*d*. for manures and lime directly applied (out of a total cost of £136, 0*s*. 3*d*.), £125, 0*s*. 4*d*. for manures, &c., previously applied, and £50 for cleaning costs.

The method of distribution of cleaning costs—mainly incurred on the root crops—can also be better discussed under root crops, but it so happens that on this farm there is a very clear case for charging a fair share of these costs against oats. Although the oat crop is the money crop, the root crop is nevertheless the central crop in the rotation.

The charge for **rent and rates** was arrived at by dividing the total rent and rates, *less* the rental value of the dwelling-house and workers' cottages, by the total number of acres. The fields do vary considerably in productive capacity, but, in general, each season's oat crop acreage contains a fair proportion of the various qualities.

It may be noticed that income tax has not been included, as it is not a legitimate charge in a cost sheet.

Little need be said on the matter of **general expenses** except that they are based upon actual payments shown by the ledger accounts. Of the binder twine £18, 16*s*. was for cutting and the remainder for threshing—only part of the straw, however, being " bunched ".

Interest has been charged at the rate of 6 per cent per annum on £12 per acre, being the proportion of the total capital due to be carried by the oat crop, while the **management** charge of 17*s*. per acre is based upon a managerial salary of £300 for the whole farm (300 acres arable and 8 acres bog-land), of which one-half was allocated to the live stock and one-half to crops.

The **yield** of grain includes both firsts or " tops " and seconds (of good feeding quality), but the thirds or lights have been ignored, on account of their very low feeding value. The yield of straw is, of course, partly an estimate, but the crop off one over-average field of 11 ac. was threshed and baled shortly after harvest, fully 2 tons per acre of straw being sold.

It will be seen that the *net farm cost* amounts to £12, 11*s*. 10*d*. per acre or 28*s*. per quarter, while the *gross farm cost* is £14, 3*s*. 3*d*. per acre or 32*s*. 9*d*. per quarter. In arriving at the cost per quarter straw has first of all been credited at £2 per ton or £3, 10*s*. per acre, being its

estimated farm value. If the straw were priced according to the relative market prices of the grain and the straw, the credit would have been about £4 per acre, but although—owing to the large crop—fully 60 tons of straw were sold, it appears fairer to adopt 70*s*. per acre for costing purposes.

It is, of course, desirable to show both the cost per acre (*acre cost*) and the cost per quarter (*yield cost*), but in some respects the former is the more significant.

Of the various factors in production, seed, manures, rent and rates, interest and management—representing in this case nearly 50 per cent of the gross cost—bear almost as heavily on a small as on a large crop, while the remaining factors vary in cost, although not directly, according to the size of the crop.

The yield again depends largely upon the weather; hence we reach the conclusion that the acre cost is more completely under the farmer's control than the yield cost, and therefore may be a better test of the efficiency of the methods of production. On the other hand, the final economic test should be the yield cost over a period of, say, eight years, i.e. long enough to eliminate the effect of the weather. The fact that in any one season the effect of the weather varies from district to district is a further reason for comparing acre costs rather than yield costs—at least in the first place.

The last two columns in the cost statement, showing the percentage of each item in the gross and also in the net cost, are probably surprising to those who have never worked out the problem in this way. Man labour forms only 24½ and 27½ per cent respectively of the gross and net farm cost, while for horse labour the corresponding figures are 11½ and 13. In other words, a variation of 10 per cent in wages—or rather in the cost of labour, which is not necessarily the same thing—would affect the total cost per acre by only about 2½ per cent. The relative unimportance of rent and rates (7¾ per cent of the gross cost) and the large percentage (16 of the gross cost) formed by general expenses are also rather striking. In connection with the latter item it is of interest to note that a provisional estimate of cost, made before the ledger accounts were completed, considerably understated the charge both for repairs and renewals and for establishment expenses.

Space forbids a fuller discussion of the interpretation of this particular example. It will be obvious from the data given below that no general conclusions can be drawn from a single farm. In particular, nothing will be said about two important aspects of the farm management problem on which cost accounts throw a clear light, viz. (1) the number of days (or hours) of man and of horse labour required to produce, say, an acre or a quarter of oats under different conditions of soil, climate, management, &c., and (2) the distribution throughout the year of

TABLE SHOWING COSTS OF PRODUCTION OF THE SCOTTISH OAT CROP—SEASON 1920

Case No.	1		2		3		4		5	
District	South		West.		West		East.		North	
Number of Acres grown	90		30		18		120		110	
Factor.	Cost per Acre.	Per Cent Gross Cost.	Cost per Acre.	Per Cent Gross Cost	Cost per Acre.	Per Cent Gross Cost	Cost per Acre.	Per Cent Gross Cost	Cost per Acre.	Per Cent Gross Cost
	£ s. d.		£ s. d.		£ s. d.		£ s. d.		£ s. d.	
Labour—Man	2 6 8	16·8	5 4 8	30·9	2 7 4	14·1	3 0 11	22·2	1 12 8	17·0
Horse	1 14 7	12·6	2 12 4	15·5	1 3 6	7·0	1 12 8	11·8	1 10 10	16·9
Total labour	4 1 0	29·4	7 17 0	46·4	3 10 10	21·1	4 13 4	34·0	3 3 6	34·8
Seed	2 1 4	15·0	1 10 4	11·7	2 16 0	16·9	1 19 8	14·4	1 14 1	18·7
Manures and cleaning costs	3 1 0	22·1	2 6 9	13·8	4 10 5	27·0	3 0 6	22·1	1 2 11	12·6
Rent and rates	1 6 0	9·4	1 8 8	8·5	1 15 0	10·4	1 5 0	9·1	0 17 0	9·3
General expenses	1 13 9	12·3	1 16 8	10·8	2 7 7	14·2	1 11 1	11·3	0 19 11	10·9
Net farm cost	12 3 1	88·2	15 8 5	91·2	14 19 10	89·6	12 9 4	90·9	7 17 8	86·3
Interest—6% per annum ..	0 14 6	5·3	0 15 0	4·4	0 17 0	5·1	0 13 0	4·7	0 12 0	6·6
Management	0 18 0	6·5	0 15 0	4·4	0 18 0	5·3	0 12 0	4·4	0 13 0	7·1
Gross farm cost ..	13 15 7	100·0	16 18 5	100·0	16 14 10	100·0	13 14 4	100·0	9 2 8	100·0
Yield per acre—Grain ..	40¾ bus.		24 bus.		35 bus.		45 bus.		27½ bus.	
Straw ..	30 cwt.		26 cwt.		30 cwt.		28 cwt.		12 cwt.	
Credit for straw	£3 per acre		£5 per acre		£4. 10s. per acre		£3 per acre		£1. 4s. per acre	
Net farm cost per quarter ..	29s. 6d.		69s. 5d.		47s. 11d.		33s. 8d.		38s. 8d.	
Gross farm cost per quarter	34s. 10d.		79s. 5d.		55s. 11d.		38s. 1d.		46s.	
Cost of marketing grain	1s. per quarter on 300 qr.		10d. per quarter on 30 qr.		Included in above (low)		Included in above (⅓ sold)		Nearly all consumed on farm	
Cost of horse labour ..	8s. 11d. per day		8s. 3d. per day		6s. 1d. per day		7s. per day		7s. 5d. per day	

Note.—Quarter = 8 bus. of 42 lb. All yields given to the nearest quarter-bushel

the labour required by different crops—a question of vital importance in farm management.

A word must be said, however, as to the application of such figures as the above to current conditions. The farmer is chiefly concerned about future rather than about past costs, and it is important to consider whether past costs can be used as a guide to probable costs in the immediate future. Two examples must suffice to indicate the procedure from this point of view.[1] First, it was found that 73 per cent of the cost of horse labour for the season 1920 consisted of food costs, and that horse labour cost £1, 12*s*. 8*d*. per acre. If now it is estimated that the foods used by horses during the season 1921 cost, say, 70 per cent less, it is purely a matter of arithmetic to work out the effect of this reduction upon the cost per acre. Second, the effect of a decrease of, say, 30 per cent in the cost of seed can be at once determined. In fact, this particular farmer can go through his detailed cost statement and estimate the probable cost per acre of 1921 or 1922 oats with some degree of accuracy, whereas ordinarily any such estimate would be chiefly guesswork, especially so far as labour and general expenses are concerned. The old Scotch saying that "he who counts the cost will never yoke the plough" no doubt had its origin in the general inability to count it correctly.

It should now be possible to present certain actual costs of grain crops without danger of these being misinterpreted and misused. The table on p. 313 gives five further examples for the 1920 oat crop in Scotland obtained under the same scheme as the example already discussed.

In this table no attempt has been made to select cases showing approximately the same costs either per acre or per quarter; rather the object has been to give examples from different districts without in any sense suggesting that they are necessarily average costs for these districts. It will be seen that, as generally recognized, there is a wide variation in costs per acre, yields per acre, and costs per quarter, but it is also evident that there is considerable variation in the relative importance of the various cost items. This table is further referred to in the notes given below.

A considerable mass of cost data has been obtained in Scotland under the general costings scheme initiated by the Agricultural Costings Committee and latterly carried out by the Board of Agriculture for Scotland, under whom the writer was responsible for the work done in Scotland. It is not possible, for various reasons, to discuss the results of this scheme in any detail, but the following table gives a few examples of fairly typical cases for wheat, barley, and beans.

[1] A more complete discussion, by the present writer, of this aspect of the case will be found in the *Scottish Journal of Agriculture*, July, 1922.

TABLE SHOWING COSTS OF PRODUCTION OF SCOTTISH WHEAT, BARLEY, AND BEAN CROPS—SEASON 1920

	Wheat.		Barley.		Beans.	
Case number ..	6	7	8	9	10	11
District	S.E.	East.	S.E.	East.	S.E.	East.
Acres grown ..	21½	13	60½	44¼	4	5
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Net cost per acre ..	15 6 8	10 3 4	13 5 6	16 4 1	26 9 8	20 9 2
Gross " " ..	16 14 3	12 5 2	14 14 11	18 15 1	27 19 1	23 10 2
Yield per acre: grain	32 bus.	24 bus.	35 bus.	49¾ bus.	31 bus.	23 bus.
straw	20 cwt.	18½ cwt.	11½ cwt.	33 cwt.	25 cwt.	16 cwt.
Straw credited at	40*s*. per acre	37*s*. per acre	23*s*. per acre	66*s*. per acre	50*s*. per acre	24*s*. per acre
Net cost per quarter	66*s*. 8*d*.	55*s*. 5*d*.	55*s*. 5*d*.	41*s*. 6*d*.	123*s*. 10*d*.	134*s*.
Gross " "	73*s*. 7*d*.	69*s*. 5*d*.	62*s*. 2*d*.	49*s*. 8*d*.	131*s*. 5*d*.	155*s*. 2*d*.

Note.—Above costs include cost of marketing grain sold. Bushel = 63 lb. of wheat and beans, and 56 lb. of barley.

Attention may be briefly called to certain points arising out of these tables, viz.:

1. In most cases an examination of the original records offers a clear explanation as to why individual costs are abnormally low or high.

2. The foregoing data do not in any sense indicate the relative efficiency of the various farmers or of their methods of management. For example, case No. 3 is a very well-managed farm, on which the aim is, by the use of the varieties proved to be best suited for the district, by liberal manuring, and so on, to produce a crop of about 60 bus. per acre, and it was entirely due to the late season and unfavourable harvest that it was only 35 bus. Further, as already indicated, figures dealing only with grain crops may give misleading impressions as to the soundness of the general farm economy, and especially when they relate to only one year.

3. It will be seen that the costs per acre do not vary to the same extent as the costs per quarter. It is safe to assume that the farmers here concerned make their plans and incur costs sufficient to produce really good crops, but all such plans are liable to go astray, either through unfavourable weather at a critical stage in the growth of the crops, through insect attacks—wireworm, leather-jacket, frit fly, &c.—or through a stroke of bad luck, e.g. getting seed of low germinating capacity. There is a distinct tendency for high yields and low costs per quarter to occur together, but, on the other hand, low yields may accompany low costs per quarter.

In any case figures from such farms, which are all on the whole well managed, do not cover the whole problem involved in this question. It is fairly certain that high costs per quarter will result from low yields in all cases where the treatment has been such as to produce high yields, given suitable weather, freedom from disease and insect attacks, &c., but this by no means proves that the same will hold true where the farmer aims at producing only small to medium crops.

4. The credit given for the straw varies according to the local conditions. Thus for oats it is usually about £2 per ton, but in case No. 2 it is nearly £4 per ton, because on this farm the crop is grown largely for the sake of the straw and only a moderate yield of grain can be reckoned on.

5. It must be firmly kept in mind that all these costs refer to season 1920 only.

The writer is not in a position to put forward any costs from England or Wales; indeed, so far as the main object of this article is concerned this is scarcely necessary. Conditions in England vary even more than they do in Scotland, and sufficient data to enable true average costs being obtained in any district or for the whole country are not in existence. The reader may, however, be referred to *Minutes of Evidence*, Vol. III (Cmd. 391, 1919) of The Royal Commission on Agriculture, for data referring to 1918 and 1919 crops throughout England and Wales, and also to Vol. IV (Cmd. 445, 1919) for similar data referring to 1918 crops in Scotland. The figures in these volumes are, of course, chiefly estimates, although a certain number are taken from detailed records.

Lastly, a brief reference may be made to future and also to pre-war costs.

No data, based upon detailed costing records, are available for 1921 crops, and it is, of course, impossible to give even approximately certain estimates for 1922 crops, since the costs of harvesting, threshing, &c., and also the yields per acre are still problematical. In so far as this article is chiefly concerned with a brief statement of some of the more important economic principles involved in farm costing, the lack of more recent data than those given is no serious drawback; but in so far as readers are interested in costing chiefly as a means whereby they may be enabled to analyse existing conditions, it is unfortunate that the machinery by which data for 1921, 1922, and future crops would have been produced has now been scrapped.

As regards pre-war costs little can be said, since no actual cost data for Scotland are on record. This is unfortunate, as pre-war costs would have indicated to what extent the relative importance of the different cost factors varies according to general economic conditions. For example, on the farm exemplified on p. 309 the gross cost of the 1914 oat crop was estimated to be £6, 9*s*. 3*d*. per acre. Of this amount rent

and rates formed 19*s.* or nearly 15 per cent, compared with less than 8 per cent in 1920, while seed cost 14*s.* 6*d.* per acre or fully 11 per cent, as against $13\frac{1}{2}$ per cent in 1920. At any rate definite conclusions on this aspect of the costing problem would require to be based upon several years' records.

Akin to this problem is the question as to the relative importance of the various cost factors on soils of different productive capacities. It is obvious that the cost of ploughing 30-bus.-per-acre land may be as great as or greater than that of 60-bus.-per-acre land, i.e. the pressure of labour costs is likely to be greatest upon lands of low productivity. But only complete cost records over a series of years would show exactly the true state of affairs.

Hence this article may appropriately conclude on a note of interrogation. Few questions on farm economics and management in this country can be answered in the light of actual and authentic data, and there is a crying need for further and extensive research into this poorly cultivated but very fertile field.

PARASITIC FUNGI OF CEREALS

By H. WORMALD, D.Sc., A.R.C.Sc.

The depreciation in the value of the cereal crops throughout the world due to the ravages of parasitic fungi amounts to many millions of pounds sterling annually. Some of the more destructive of these organisms are of common occurrence and widely distributed; others are sporadic, and, though sometimes causing great damage locally, do not become widespread or general; while still others, though common and widely distributed, do little damage beyond causing slight injury to the leaves.

Methods that are commonly adopted in combating the parasitic fungi on other crops, such as spraying with fungicides, dusting with sulphur, the excision of diseased organs, and the uprooting of affected plants, are obviously impracticable on a large scale in cereal crops. There are, however, well recognized means of keeping under control many of the diseases caused by parasitic fungi on cereals. These methods include: (1) breeding, to obtain cereal varieties resistant or immune to specific diseases; (2) seed-treatment, with the object of destroying the parasite or its spores without impairing the germination of the seed; (3) selection of seed corn from fields where disease is not known to occur; (4) taking care to avoid growing a crop in fields the previous history of which suggests the possibility of the presence in the soil of resting spores of fungi which attack that crop; (5) destruction of weeds which serve as hosts for the parasitic fungi; this includes the removal of the alternative host plants of those rusts which have two distinct hosts, e.g. the barberry in the case of black rust.

The control of certain diseases of cereals is not easy, and probably the only reliable preventive measures in such cases will prove to be the raising of resistant varieties. Valuable work has already been done in

this direction, and Professor Biffen has proved that it is possible by breeding operations to raise new varieties in which rust resistance is combined with other desirable qualities. Thus the now well-known variety Little Joss, which shows considerable resistance to yellow rust, was obtained by crossing Ghirka, a Russian disease-resisting variety, with Squarehead's Master. On the other hand, there are some diseases, e.g. certain smuts, which, though very destructive if allowed to go unchecked, are easily preventable by measures which should be practised by all growers of cereals. Striking figures illustrating this point appear in the *Yearbook of the United States Department of Agriculture* for 1917, where it is stated that " those diseases most easily subject to control are the smuts which to-day, according to reasonably conservative estimates, are annually destroying 20,000,000 bus. of wheat, upwards of 50,000,000 bus. of oats, and 6,000,000 bus. of barley ". It is evident that when suitable control measures become universal, losses on such a scale will be avoided.

Fungous Diseases of Wheat

Black Rust.

Black rust, caused by *Puccinia graminis* Pers., is a disease of cereals which is of world-wide distribution. When, as is often the case, it assumes epidemic proportions the adverse effect on the yield is considerable. Thus it has been estimated that in the United States the wheat crop of 1916 was reduced by 180,000,000 bus., while in the same year the loss in Canada amounted to about 100,000,000 bus. In Australia the wheat crop, as a result of this disease, is reduced in value annually by about £1,000,000, while in seasons favourable to the disease the loss may be from 2 to 3 million pounds sterling.

Though black rust is not generally so prevalent in Britain as certain other cereal rusts, it sometimes develops to a serious extent, as shown by the outbreaks which occurred in Pembrokeshire during the years 1915–8, when in some instances crops were reduced by about 50 per cent.

Puccinia graminis is a " heterœcious " fungus, that is, to complete its full life-cycle it requires two different hosts. The alternative host plant in this instance is usually the common barberry (*Berberis vulgaris*), though *Mahonia aquifolium* also sometimes serves as the other host. Observations have shown, however, that black rust is able to persist from year to year in regions where the stage on barberry does not occur. In Australia, where the rust is very prevalent, the barberry is not a native plant, and imported barberry bushes have not been attacked by the disease; again, in India wheat is infected by black rust year after year in districts hundreds of miles from the nearest barberry bushes.

Black rust not only attacks wheat, oats, barley, and rye, but also a large number of wild and fodder grasses, and, until a few years ago, it was generally considered that the rust occurring on any one of these hosts could infect any of the others. Recent work has shown, however, that there are several " specialized " or " biologic " forms of the fungus which are more or less restricted to their respective hosts. According to Professor Eriksson the black rust of wheat is practically confined to wheat, but occasionally goes over to other grasses; it seldom occurs on oats, barley, or rye, though another form infects rye and barley but not wheat or oats, while a third form infects oats but not the other cereals.

There are three stages in the life-history of *P. graminis*; two of these occur on the cereal or grass, the third on barberry or Mahonia. On wheat the rust spots become noticeable early in June as raised yellow-brown streaks about $\frac{1}{10}$ in. in length when produced singly, but on becoming confluent they may reach a length of $\frac{1}{2}$ in.; they may be found on both surfaces of the leaves, on the leaf sheaths, on the stems, and even on the ears. The spots at first appear as elongated pustule-like swellings beneath the epidermis, but when this is eventually ruptured the summer spores, or *uredospores*, are exposed and become dispersed.

The uredospores are one-celled, and their outer coating is covered with minute spines. Each spore is borne on a short stalk, but when mature it soon becomes detached and may be carried in the wind for some distance; on reaching another wheat plant it will, under suitable conditions of temperature and moisture, germinate immediately and produce a germ tube penetrating into the host plant, which thus becomes infected with the disease, and in its turn produces new patches of rust spores within about ten days.

About the end of July the winter spore, or *teleutospore*, stage appears. The spots are similar to those of the uredospore stage except that they are black in colour, hence the popular name of this disease. Teleutospores often follow the uredospores on the same spots, which thus gradually change from brown to black as the uredospores become replaced by the teleutospores. The latter are two-celled and have thick, smooth walls; they are borne on short stalks, to which they remain attached unless forcibly removed. These winter spores do not produce infection directly, but, after exposure to the ordinary atmospheric conditions in the open during the winter, they germinate in the following spring. Each of the two cells of the teleutospore on germinating gives rise to a short germ tube or *promycelium*; this becomes transversely divided into four cells, from each of which a short outgrowth (*sterigma*) develops and bears terminally a minute spherical spore or *sporidium*.

The sporidia germinate readily in moist air, but are unable to infect wheat. On a barberry leaf, however, the germ tube of a sporidium

penetrates the epidermis and the fungus grows within the tissues of the leaf, producing finally another kind of fructification. This stage in the life-cycle of the fungus is known as the *æcidial* or cluster-cup stage, from the form of the fructification. The æcidia are formed beneath the lower epidermis, and are at first more or less spherical, with a wall (*peridium*) consisting of a layer of cells, but as maturity approaches the epidermis is ruptured, and the peridium bursts open to form a fringed margin to the now cup-shaped fructification, from the base of which rise closely packed rows of spores, the *æcidiospores*.

The æcidia are produced in small clusters, forming yellow patches to about $\frac{1}{3}$ in. in diameter; they are to be found not only on the leaves but also on the fruit of the barberry. On the upper side of the leaves small flask-shaped bodies (*spermogonia*) are also to be found, the necks of which pierce the epidermis. The function of the minute sporelike *spermatia* set free from the spermogonia has not yet been determined.

The æcidiospores on being set free from the cluster-cups are disseminated by the wind; under suitable conditions they germinate directly, but, like the sporidia, they are unable to infect the host plant on which they are produced, and their function in the life-cycle of the parasite is to establish the fungus once more on the wheat. When germinating on a wheat leaf the æcidiospore gives rise to a germ tube, which enters the leaf through a stoma, and develops a mycelium which grows between the cells of the leaf; short branches also penetrate the cell walls to form suckers, or *haustoria*, within the cells themselves. After growing within the tissues of the leaf for a few days the mycelium produces, just under the epidermis, tufts of short hyphæ, each of which gives rise terminally to a spore, and the uredospore stage again appears.

As the uredospores falling on the plants around germinate at once, and give rise to further infection with a fresh crop of spores within a fortnight, it is easy to conceive how, under conditions favourable for the dispersal and germination of the spores, the disease extends rapidly through a field.

Yellow Rust.

Puccinia glumarum Eriks., the yellow rust fungus, is another very common parasite of cereals. Though not so widely distributed as *P. graminis* it is known to occur in Europe, Egypt, North America, India, and Japan. As in the case of the black rust it includes several biologic forms infecting respectively wheat, barley, rye, and certain grasses.

In some districts of England it is known as spring rust, for, as a rule, it appears earlier in the season than the black rust; on wheat in some seasons it may be observed as early as February. It forms numerous small oval patches, lemon-yellow to orange in colour, produced in long lines along both surfaces of the leaves, and in severe attacks may extend

to the sheath and the stem, while sometimes the ears are seriously affected. This is the summer stage, and the uredospores, on being liberated by the rupture of the epidermis, are able to induce further infection on the same or neighbouring plants. The uredospores of the yellow rust are globular in form, and so may be distinguished from the oval uredospores of the black rust.

Later, two-celled teleutospores, at first brown, then black, are produced in lines on the under surface of the leaves and on the sheaths, but in this case they remain covered by the epidermis. The teleutospores germinate after a short resting-period, and give rise to promycelia and sporidia, but the latter, so far as is known, cannot infect any plant whatever. An alternative host for this fungus has not been discovered, and an æcidial stage is not known to exist.

Brown Rust.

A third rust which frequently causes damage to wheat in Britain, and one which is practically of world-wide distribution, is the brown or orange rust, *Puccinia triticina* Eriks. No other host is known for this fungus, as it does not pass over to any other cereal or grass, and no æcidial stage has been discovered either on wheat or on any alternative host.[1]

The uredospore stage may be found early in spring on wheat leaves as small scattered patches, at first orange, later dark brown in colour. This is succeeded by the teleutospore stage which appears as short, black lines mostly on the under surface of the leaves, but they may also occur on the sheaths. The teleutospores remain covered with the epidermis of the leaf and do not germinate until the following spring.

Preventive Measures against Rust.—The nature of the crop and the rapidity with which, under favourable atmospheric conditions, the rust fungi are transmitted from plant to plant during the uredospore stage, render impracticable any measures for dealing with the diseases when once they appear in a field. Low-lying poorly drained soils should be avoided whenever possible, as excess of moisture during the warmer days of spring is particularly favourable for the spread of rusts. Grasses which might serve as hosts for cereal rusts should be kept down in the neighbourhood of the crops.

Since the barberry is a host for *P. graminis* it is evident that it may prove a dangerous source of infection, and so should be eradicated. In Denmark the destruction of barberry bushes was made compulsory in 1903 with highly beneficial results. It is to be remarked in this connection that a considerable number of wild barberry bushes were found in the neighbourhood where the severe attacks of black rust occurred in

[1] While this article was in the press, two American botanists published results of experiments in which the æcidial stage of *P. triticina* was produced in greenhouse cultures upon several species of Thalictrum (see *Jour. Ag. Res.*, XXII, p. 151, Oct. 1921).

Pembrokeshire in 1915–8, and their uprooting was therefore recommended.

In districts where a rust has been prevalent in past years, varieties resistant to the disease should when possible be selected for sowing; it is to be observed, however, that a variety which is resistant to one kind of rust is not necessarily resistant to others. The treatment of the seed with chemicals, such as are effective against some smuts, is useless in the case of rusts.

Wheat Smuts.

The smuts are the most conspicuous and striking of all the parasitic fungous diseases to which cereals are subject, and the blackened grains and soot-like powder appearing on the ears must be familiar to all who have grown grain crops on any considerable scale. On wheat, oats, and barley the smuts are of frequent occurrence and often cause serious damage; the fungi responsible for these diseases live within, and grow up with, their host plants without at first producing any marked injury, but, as the ears develop, the fungi penetrate the grains, the contents of which become replaced by a black mass of spores. Rye is also attacked by smut diseases, which, however, are less frequently met with than those of the other cereals.

Some smuts may be controlled effectively and easily by treating the seed corn with certain chemicals; the necessary treatment in the case of other smuts is less easily carried out, and usually the selection of seed from clean crops will prove the most desirable method of dealing with these. It is necessary, therefore, that the practical farmer should be able to distinguish between those smuts that readily yield to treatment and those which do not.

Stinking Smut of Wheat.

This disease, also known as bunt or slayne, is caused by *Tilletia tritici* (Bjerk.) Wint., or occasionally by *Tilletia levis* Kuehn. These two species are similar in their life-history and mode of parasitism, and are only distinguishable microscopically, the former having spores with raised ridges forming a network over the surface, while the latter has smooth spores. Plants attacked by bunt outwardly resemble the healthy plants until harvest-time approaches, when the ears are paler in colour and the glumes (or chaff scales) are more spreading than in the normal plants. It will then be found that the grains of such ears are grey, plump, rather soft (therefore easily broken by slight pressure between the thumb and finger), and shorter than healthy grains, their shape being more nearly spherical than that of the latter. On breaking the thin skin of these bunted grains the interior is seen to be composed of a mass of soot-like powdery granules which are easily blown away. The black powder consists of innumerable spores, which, on being set free by

threshing operations or other mechanical means, become scattered over the sound grains, to which they cling, many being caught in the tuft of hairs at the apex of the wheat grain. The bunt spores are sometimes so numerous that a sample of the wheat is distinctly darker in colour than a sample from a clean crop, the grains, and particularly the hairs, presenting a very dirty appearance. If a few of the bunted grains are crushed in the hand an odour of tainted fish is emitted, this being a characteristic feature of the disease.

It is evident, therefore, that seed taken from an infected crop will carry spores of the fungus when sown. The spores have a thick dark brown coat, but germinate readily in water within a few days. Each spore gives rise to a germ tube bearing terminally a tuft of elongated thin-walled spores, or *sporidia*, which are usually united in pairs by short connecting tubes; these sporidia may under certain conditions produce secondary, sickle-shaped sporidia. Both primary and secondary sporidia form germ tubes, which are capable of penetrating the young wheat shoot as it emerges from the grain.

The fungus continues its growth within the young wheat plant without materially affecting its host until the ears develop, when it enters the grains. Living at the expense of the materials found there, and having consumed all the food available, the fungal hyphæ within the grains eventually divide up into short cells, which become rounded off, develop thick walls, and so form a large number of dark brown spores (known as *chlamydospores*). These in the mass appear black, and form the soot-like powder found in a bunted grain. The outer layers of the grain remain to form the thin skin which prevents the immediate dispersion of the spores.

Treatment.—Bunt can easily be kept under control by treating the seed wheat with certain solutions, which, when used at a suitable strength, will kill the bunt spores adhering to the grains without materially interfering with the germination of the seed. Up to the present, formalin has proved to be the most convenient and effective solution for this purpose. Formalin is a solution of the gas formaldehyde in water, and is usually supplied by chemists at a 40 per cent strength. At this strength it should be diluted at the rate of 1 part in 240 parts of water, e.g. $\frac{1}{2}$ pt. in 15 gall. or, for smaller volumes, 1 fluid oz. to $1\frac{1}{2}$ gall. This diluted solution is sprinkled over the seed wheat and well stirred in until the whole has been wetted; this will require about 1 gall. of the solution for every 2 bushels of seed. The treated wheat is then put in a heap, covered with sacks which have been wetted with the same solution, and left for four hours, after which it is spread out to dry and then sown as soon as possible.[1]

[1] Since writing the above, experiments carried out at the S. E. Agricultural College, Wye, have shown that Bunt can be effectively controlled by weaker solutions of formalin, viz. 1 : 320 or even 1 : 480.

A 2·5 per cent solution of copper sulphate may also be used, e.g. 1 lb. of copper sulphate (bluestone), which should be of 98 to 99 per cent purity, dissolved in 4 gall. of water. This should be sprinkled over the seed and stirred in until all the grains have been wetted, when the seed should immediately be spread out to dry. At this strength the copper sulphate solution is not quite as efficient as the formalin solution recommended above, and to increase the concentration of the copper sulphate is not to be advised, as the germination of the seed will be adversely affected.

Loose Smut of Wheat.

The loose smut, *Ustilago tritici* (Pers.) Jensen, is easily distinguished from bunt from the fact that the affected ears are conspicuous as soon as they appear from the ensheathing leaves. The diseased grains, full of black-looking spores, soon burst, giving the ears a sooty appearance and the spores are scattered by the wind or washed away by rain until there is little left but the bare rachis. The spores are much smaller than those of the stinking smut, and are very easily carried in the wind. They are dispersed about the time the wheat is in bloom, and some reach the open flowers of the plants around and are caught on the stigmas. There they germinate and the germ tubes enter the immature grains. A grain infected in this way is not killed but continues its development, and when mature is, as a rule, indistinguishable from sound grains.

While the corn is kept dry the fungus remains in a dormant state, but when it becomes moistened, as would happen when it is sown in ordinary damp soil, the parasite resumes its activity, and as the seed germinates grows up inside the young plant. It extends along the stem and finally into the ears, transforming the young grains into black masses of spores, which in their turn are dispersed by the wind and infect the new crop.

Treatment.—Since the loose smut fungus is already *within* the grains at the time of harvesting, such treatment as is applicable to bunt (the purpose of which is to destroy spores on the *outside* of the grains) is ineffectual.

It has been found, however, that, by first soaking the seed in water and then heating it to a certain temperature, it is possible to kill the fungus without injuring the grain. Various methods have been elaborated for so heating the seed, and some modification of Jenson's hot-water treatment is generally adopted when treatment for loose smut is necessary. The hot-water method has been employed with success in Denmark and Holland, but up to the present has not been favourably received in this country, because of the labour involved in treating large quantities of grain, and the great care that must be exercised in maintaining the proper temperature.

Mercer recommends the following: The grain, in sacks, is allowed to stand in cold water for 4 hours. The sacks are then transferred to a tank of water at 52° to 54° C. (125° to 129° F.), and heaved up and down for 10 minutes; this removes the air and allows the hot water to come in contact with all the grains. The corn is then taken from the sacks and spread out to dry.

The chief difficulty is in maintaining the exact temperature; an accurate thermometer must be placed in the water of the tank and kept continually under observation. If the temperature is not maintained the treatment will be ineffectual, and if it is exceeded the percentage of seed capable of germination will be reduced. Supplies of hot and of cold water should be at hand, so that variations in the temperature of the water may be adjusted immediately.

Such control measures are unnecessary if the farmer is able to obtain his seed corn from fields where the disease is absent, and it is obvious that the sowing of seed taken from infected crops should be avoided whenever possible.

Mildew.

Erysiphe graminis D. C., the mildew of cereals and grasses, consists (as in the case of the rusts) of several specialized forms, one of which infects wheat and other species of the genus Triticum. The disease causes a discoloration of the leaves, and a whitish mould appears on the affected parts; in severe attacks the leaves become deformed, and premature ripening with the production of light ears with shrivelled grains is a result. It may in certain seasons cause considerable damage, as in California in 1877, and in Sweden in 1885; in this country it is sometimes responsible for serious reductions in the yield of wheat, as in the outbreaks which occurred in Cheshire in 1918, when instances of diminished yield estimated at probably 40 per cent were recorded.

The mildew is to be found mostly on the upper surface of the leaves, but may extend to the lower side and also to the sheaths and stem. It forms, at first, white powdery patches which later become grey, pale brown, or reddish. The powdery spots make their appearance early in spring, and at this stage the fungus produces numerous chains of oval conidia, which, on being dispersed by wind, rain, or insects, serve to spread the disease during spring and early summer.

A conidium on falling upon a leaf will, under favourable atmospheric conditions, germinate and give rise to a germ tube, the end of which swells out to form an *appressorium*; this becomes firmly attached to the leaf, and from it a small outgrowth develops, which penetrates the outer wall of the epidermis; on reaching the interior of an epidermal cell it swells out to form a sucker or *haustorium*. Having thus secured a hold on the host plant, the fungus proceeds to grow over the surface and to

produce other *haustoria*. Soon chains of conidia are developed and a powdery patch is seen.

During the summer the patches lose their powdery appearance, and the fungal threads (*mycelium*) form a dense greyish felt in which black dots appear. These are the spore-cases or *perithecia*. A perithecium has a thick outer wall enclosing a number (usually 15 to 20) of thin-walled sacs (*asci*), each containing 8 spores. This is the winter form of the fungus, and in the following spring the wall becomes ruptured, the asci protrude and burst at the apex, ejecting the contained spores which are capable of infecting wheat plants, and in this way the disease is started on the new crop.

To attempt to control this disease by the application of flowers of sulphur or of a sulphide-containing wash, such as is generally employed against the powdery mildews, is clearly impracticable in the case of cereals, except perhaps on small trial plots. It is advisable that the farmer should secure his seed from a clean crop; straw from a diseased crop, which probably has the winter form adhering to leaves and stalks, should not be mixed in manure which will be used for a wheat field.

"Take-all" and "White-heads".

A disease of wheat and other cereals known as "take-all" is characterized by a yellowing of the leaves and subsequent death of young plants, which usually succumb before the ears appear. If the base of the stem is examined it will be found to be blackened, and on pulling up a diseased plant a clod of soil frequently adheres round the roots, owing to the abnormal development of root-hairs.

Another condition, which is now known to be caused by the same fungus (*Ophiobolus graminis* Sacc.) attacking the wheat at a later stage in its growth, is that known as "white-heads", "night-blindness", or "straw-blight"; in this condition the plants grow to their normal height, but the grains either fail to develop at all or are small and shrivelled. Such plants are much paler than the healthy ones and in comparison appear bleached. At this stage the plants are dry and dead, and the stem is blackened from the base upwards for a distance of 1 to 3 in. As the disease is the result of infection near the ground level, followed by the characteristic blackened appearance of the "foot" of the stem, it is referred to on the Continent in terms signifying "foot-rot", e.g. "maladie du pied", "Fusskrankheit des Getreides", or "mal del piede del grano".

The blackening is due to the presence of a thin felted layer of brown mycelium girdling the stem. During the autumn and winter this mycelium continues its development on the stubble, and produces numerous fructifications seen as small, black wart-like bodies projecting from the weft of fungal threads. When mature, the fructifications contain a number

of thin-walled elongated sacs (*asci*), each of which liberates eight needle-shaped spores; these are set free in winter or spring, and, under favourable conditions of moisture and temperature, germinate and infect any suitable host plant with which they come in contact.

Where practicable, such infected stubble should be burnt in order to destroy the fruiting stage of the fungus. Rotations with long intervals between the cereal crops should be carried out in infected fields, and care should be taken to keep the field clean in the meantime from wild grasses, some of which are known to be susceptible to the disease and would therefore carry it over to the cereal crops. Superphosphate is to be recommended as an artificial dressing for infected soil, as it has been found to check the growth of the fungus.

Black Mould or Blight.

As harvest-time approaches, wheat is frequently found to be infested with black mould occurring as small blackish spots arranged in lines or forming scattered patches on the leaves and stems, and often particularly noticeable on the chaff scales, while it may also extend to the grains themselves. In severe attacks the leaves become yellowish and later more or less withered, and the grains are small and shrivelled. The disease is most prevalent during wet seasons and in damp low-lying situations.

Each black spot of mould consists of a tuft of erect olive-coloured fungal hyphae producing reproductive bodies (*conidia*) at their tips. The conidia are pale olive in colour, oval, and usually two-celled; on being dispersed by wind or rain to other plants they serve to spread the infection. The fungus is usually referred to as *Cladosporium herbarum* Link., a form which, unlike the rusts and smuts which are wholly parasitic, often exists as a saprophyte and has long been known as occurring commonly on dead plant tissues. Janczewski has shown that *Cladosporium herbarum* is but the conidial stage in the life-history of an ascus-bearing fungus *Sphaerella Tulasnei*. A form *Hormodendron cladosporioides* is often associated with *Cladosporium*, and is considered to be another conidial stage of the same fungus.

Lopriore finds that wheat plants may be attacked by *Cladosporium* at four stages in their development. (1) The young seedlings may become infected and killed outright. (2) The lower portion of the stems of the growing plants may be attacked, in which case the plants are weakened and produce poor ears. (3) The ears themselves if infected at the time of flowering fail to develop grains. (4) The ripening ears when infested by the mould produce small shrivelled grains.

The saprophytic habit of the mould fungus, enabling it to live on dead vegetable matter, renders the control of this disease difficult. The farmer may, however, take the precaution of procuring his seed corn from crops which were free from mould, and he should avoid, as far as

possible, mixing the straw from a mouldy crop with manure that is to be used for a cereal crop.

Fungous Diseases of Oats

Oat Smuts.

Oats are attacked by two species of smut fungi, which, however, are so similar in their life-history and mode of parasitism that, from a practical point of view, they may be considered as one form, particularly as both can be kept under control by treating the seed with formalin solution.

The loose smut of oats, *Ustilago Avenæ* (Pers.) Jensen, is to be observed as soon as the ears appear. The affected ears are narrower than the healthy ones, and usually all the spikelets are blackened and much shorter than the normal ones, though occasionally several of the spikelets at the upper end of a diseased ear remain unaffected. The grains of such blackened ears have become transformed into soot-like masses consisting of innumerable minute, globular spores, each with a thick wall bearing minute warts or spines. These spores are dispersed by the wind and rain during the summer, leaving at last almost naked stalks. Direct infection of the developing ovary does not, however, take place, as in the case of loose smut of wheat, but some of the spores are caught between the grains and glumes, and later other spores adhere to the outer surface of the husks. Thus when the seed is harvested, spores of the fungus are carried away with it. If such seed is sown the fungus spores germinate, and each gives rise to a promycelium which bears about four sporidia. The latter on germination infect the shoots of the seedling oat plants. The fungus grows up within the tissues of the young plants and finally extends into the ears, with the result that the grains become replaced by spores, which are soon blown away and caught in the ears of the new crop.

The covered smut of oats, *Ustilago levis* (Kell. and Swing.) Magn., is not of frequent occurrence in Britain. It differs from the loose smut in the fact that the diseased grains remain intact for a longer period and usually do not shed their spores before harvest-time; during the threshing operations, however, they become ruptured, and the spores are strewn over the sound grains. Microscopically it can be distinguished from *Ustilago Avenæ* by its smooth-walled spores.

Both smuts of oats can be effectively prevented by treating the seed with the formalin solution, as recommended for bunt in wheat.

Mildew.

A specialized form of the grass mildew, *Erysiphe graminis*, attacks oats and the false oat (*Arrhenatherum avenaceum*). In its morphology and life-history it is similar to the form occurring on wheat.

Crown Rust.

The crown rust of oats is so called because the free end of the teleutospore of the fungus bears a " crown " consisting of a number of blunt projections. The disease is of wide distribution, and occurs in Europe, Asia, North America, and Australia. Although the crown rust fungus, *Puccinia Lolii* Nielsen (= *P. coronifera* Kleb.), attacks a large number of grasses, including the oat, it has been shown that the species includes several specialized forms; of these the one occurring on oats and the wild oat (*Avena fatua*) is known as f. *Avenæ*.

P. Lolii is, like *P. graminis*, a heterœcious species, requiring, in order to complete its full life-cycle, a host other than a cereal or grass. In this case the other host, which bears the æcidial stage, is the common buckthorn (*Rhamnus cathartica*).

On oats the uredospore stage appears about the middle of summer. It is to be found on both sides of the leaves and on the sheaths in scattered, oblong, blister-like swellings, or the spots become confluent to form large orange patches. The yellow, spherical uredospores bear minute spines; when mature they become dispersed and cause further infection on the oats around. Later in the season the winter-spore stage of the fungus may be found on the lower surface of the leaves. The teleutospores form short black lines, or sometimes circles, round the uredospore spots, and usually remain covered by the epidermis of the leaf. They are two-celled, and the wall of the upper cell is prolonged to form the projections constituting the crown. These winter spores do not germinate until the following spring, when they give rise to promycelia bearing sporidia. The latter are able to germinate at once, but produce infection only when in contact with the leaves of the common buckthorn, where æcidia appear within about ten days after infection. The æcidiospores, on reaching the young leaves of oat plants, germinate readily, and when infection has taken place pustules of uredospores appear on the oat leaves in from eight to ten days. Since the æcidiospores are produced only on the common buckthorn, it is evident that this shrub should be eradicated in the neighbourhood of oat fields.

Black Rust.

A specialized form of the black rust fungus, viz. *P. graminis* f. *Avenæ*, attacks oats, also the false oat (*Arrhenatherum avenaceum*) and several other grasses. Its morphological characters and life-history are similar to those of the form occurring on wheat.

(For preventive measures against rusts see under Wheat Rusts.)

Fungous Diseases of Barley

Barley Smuts.

As in the case of wheat, it is necessary to distinguish between the two smuts of barley, covered smut and loose smut, if control measures are to be carried out, since the former readily yields to the formalin or copper sulphate treatment, while the more laborious hot-water method is the only direct means of dealing with the latter.

Covered smut of barley is caused by the fungus *Ustilago Hordei* (Pers.) Kellerm. and Swing. The diseased plants are at first indistinguishable from the rest, but as the ears appear these are found to be of a darker colour than the sound ears, and the plants usually do not attain to their normal height, the ears in some cases remaining partially enclosed in the ensheathing leaves. A grain taken from one of these ears will be found to consist of a thin greyish skin enclosing a black powdery mass of fungus spores; these spores are spherical or slightly elongate, have smooth walls, and are brown in colour when seen individually under the microscope. The thin pellicle surrounding the diseased grain usually remains entire until the crop is harvested, but at the time of threshing becomes ruptured, with the result that the spores are liberated and become scattered over the sound grains. If such barley is used as seed the spores clinging to the grains germinate, and each gives rise to a short germ tube or *promycelium*; this becomes transversely septate to form four cells, each of which buds off a small elongated *sporidium*. The sporidia may bud off other spores, which on germinating infect the young shoots of the barley plants. The fungus then grows up within the stem of the plant and eventually extends into the young grains, the contents of which are assimilated by the fungus and replaced by spores. The disease, as seen by the smutted ears when they " shoot " from between the leaves, thus makes its appearance in the new crop.

The formalin treatment, as recommended for bunt in wheat, will keep this disease under control. A 2·5 per cent solution of copper sulphate is also effective in considerably reducing the amount of infection.

The fungus which causes the loose smut of barley is known as *Ustilago nuda* (Jens.) Kellerm. and Swing. As the specific name implies, the spores of this fungus are exposed and dispersed early in the season, so that the affected ears become black with the soot-like powder; this is blown away by the wind or washed down by rain, leaving at last nothing but the naked rachis. Infection of the flowers takes place, as in the case of loose smut of wheat, by wind-borne spores reaching the stigmas. The germ tubes from these spores enter the young grains, which, however, continue their development, and when mature are indistinguishable from the non-infected grains. The fungus remains dormant within

the dry seed, but when this is moistened the parasite resumes its activity, and, as the seed germinates, the fungal hyphæ extend into the young shoots of the seedlings. Living within the host plant, the fungus at length grows into the ears and penetrates the grains, converting them into masses of powdery spores, which, in their turn, are set free to infect the grains of the plants around.

This disease may be controlled in the way recommended for loose smut of wheat; if the hot-water treatment is attempted a lower temperature than that employed for wheat, viz. 124° F., is to be preferred, as barley is more liable to be injured by heat than the other cereals.

Stripe Disease.

This disease, as the name implies, is characterized by the striped appearance of the leaves, the fungus causing it, *Helminthosporium gramineum* (Rabenh.) Eriks., growing in long narrow lines which are at first pale yellow, but later become darker and finally dark brown with yellow margins. " Blindness " and " deaf ear " are names that have also been applied to this disease, from the fact that the ears of plants seriously affected with stripe often fail to develop normally. In some plants the ears do not appear at all; in others, although the ears do emerge from the leaf sheaths, they remain small and distorted, and the grains do not attain to their full size. The plants may be so stunted in growth that they reach only to about half their normal height. Serious outbreaks of this disease have resulted in loss amounting to from 20 to 25 per cent.

The disease becomes noticeable quite early in the season as pale spots on the leaves and sheaths; these spots extend longitudinally to form long parallel lines, and soon the fungus produces numerous brown, upright, conidia-bearing hyphæ (*conidiophores*) which emerge through the stomata. As the conidiophores develop the colour of the streaks gradually changes from pale yellow to brown. The conidia when mature are olive in colour, and are cylindrical with rounded ends; each is transversely divided into several cells, the number of septa varying from two to seven. The conidia are easily detached from the conidiophores, and are borne in the wind to other plants; some are caught on the ears and are carried away, adhering to the grains at harvest-time. Thus, when barley obtained from a crop infected with stripe is used as seed, conidia of the fungus are sown with the grains, and the seedling barley plants become infected. The fungus grows up within the young plants, and as the leaves develop the mycelium extends into them, with the result that the leaf stripe condition reappears.

Infection of the flowers sometimes occurs by conidia which are caught on the stigmas; in such cases the germ tubes from the conidia penetrate to the ovary, and the grain becomes replaced by mycelium which may give rise to conidiophores and conidia.

A second stage in the life-history of this fungus has been described. On the dead straw and stubble small, rounded, compact masses of mycelium, or *sclerotia*, are formed; these are black on the exterior and bear numerous stiff dark hairs. The fungus passes the winter in this condition and resumes development in the spring, when the sclerotia may produce conidia, or each may develop a *perithecium* enclosing a number of *asci*, each of which contains eight ascospores. Each ascospore is divided transversely by two or three septa, and sometimes a longitudinal septum is formed. This perithecial stage of the fungus is known as *Pleospora trichostoma* f. *Hordei erecti*.

Barley that is to be used as seed should, when possible, be obtained from a crop that was free from the disease. When this is impossible, the seed should be subjected to the formalin treatment before sowing, as recommended for covered smut.

Leaf Spot or Late Blight.

Helminthosporium teres Sacc., the leaf spot fungus, produces irregular brown spots on the leaves and sometimes on the ears, which, however, do not become distorted as in the stripe disease. In its conidial stage the fungus is almost indistinguishable from *H. gramineum*. The spots which appear on the first leaves of the young plants probably arise in most instances from infected seed, and the disease spreads from such primary infections by means of the conidia which are produced on the discoloured spots; the fungus may thus rapidly extend to the succeeding leaves and to other plants around. Another stage of the fungus develops on the dead straw in the form of sclerotia, which give rise to pycnidia containing small rounded conidia.

When once the disease appears on the young leaves, nothing can be done to check the spread of the disease. Seed taken from an infected crop may give rise to diseased seedlings, infection being caused by conidia adhering to the seed. The formalin treatment, as recommended for the stripe disease, will destroy such conidia and prevent outbreaks of primary infections.

Black Rust.

Puccinia graminis f. *Secalis*, a specialized form of the black rust fungus, attacks barley, rye, and several wild grasses; otherwise it is similar to the form occurring on wheat.

Yellow Rust.

The specialized form, *Puccinia glumarum* f. *Hordei*, occurs on barley. (For further details see under Yellow Rust of Wheat, p. 321.)

Mildew.

A specialized form of *Erysiphe graminis* is found on barley. (For further details see under Mildew of Wheat, p. 326.)

Fungous Diseases of Rye

Ergot.

The disease known as ergot, caused by *Claviceps purpurea* (Fr.) Tul., is of frequent occurrence on rye and a number of fodder and wild grasses. It is of importance not merely from the direct damage which it causes to the plants which it attacks, but also because of the poisonous properties of the ergots, or *sclerotia*, of the fungus. The disease is easily recognized, as the crop is ripening by the elongated, bluish-black, horn-like sclerotia which project from the ears; these ergots are often much larger than the grains, and in rye may reach a length of from 1 to $1\frac{1}{2}$ in.

The ergots contain poisonous substances which render them extremely dangerous not only to cattle and poultry but also to human beings. The symptoms of chronic ergot poisoning, or *ergotism*, are gangrene of the extremities, convulsions, and paralysis. In countries where rye bread is one of the staple foods of the poor, epidemics resulting in deaths have broken out as a result of the consumption of bread made from ergotized rye. The principal toxic constituents of ergots are *cornutin*, *ergotinic acid*, and *sphacelinic acid*. Cornutin is an alkaloid which causes contraction of the uterus, sometimes resulting in abortion. Ergotinic acid has narcotic properties and produces paralysis. Sphacelinic acid causes thrombosis of the arterioles, resulting in gangrene.

There are several specialized forms of *C. purpurea*; the form which attacks rye also occurs on barley and a number of grasses, including sweet vernal grass (*Anthoxanthum odoratum*), false oat (*Arrhenatherum avenaceum*), tall fescue (*Festuca elatior*), and cock's-foot (*Dactylis glomerata*); thus the disease may spread from any one of these grasses to rye.

Infection takes place at the time of flowering; spores of the fungus reach the open flowers and produce germ tubes which grow into the ovary. The young infected grains soon exude a sweetish liquid, which, from its resemblance to the fluid secreted by plant-lice, is sometimes known as " honey-dew ". At this stage the fungus develops numerous oval conidia, which, on becoming detached from their stalks, remain suspended in the honey-dew. Insects, attracted by the sweet liquid, carry drops of it containing conidia to other flowers and so spread the disease. This is known as the *sphacelia* stage of the fungus. The infected grains become replaced by the mycelium of the fungus; this continues to develop to form the horn-like *sclerotia* (compact masses of fungal hyphæ), or ergots, which reach their full size at about the time

the crop is ripe, when some of them fall to the ground, where they hibernate. Many of the ergots, however, are harvested with the rest of the crop, and during threshing become mixed with the sound grains. Ergots that have been lying in the ground through the winter resume their development in the spring and give rise to a number of outgrowths. Each of these outgrowths (or *sporophores*), of which there may be ten or more from a single ergot, consists of a violet-red stalk terminated by a globular head bearing numerous dark red wart-like protuberances, each with a central pore. At the periphery of the head is a layer of flask-shaped bodies, the *perithecia*, the necks of which project to form the protuberances, and open to the exterior at the pores or *ostioles*. Within the perithecia develop elongated spore-sacs (*asci*), each containing eight filiform ascospores which when liberated may reach the flowers of a new crop, in which case infection occurs and the disease reappears.

Control Measures.—Samples of rye containing ergots should not be used as seed or the new crop will become infected, neither should they be given to cattle or poultry or ergot poisoning may result. It is necessary, therefore, to remove the ergots; if they are whole they may be sifted out, for usually they are larger than the rye grains. A more certain method, especially when small or broken ergots are present, is to float out the ergots in brine, since they are relatively lighter than sound grains. This is done by pouring the rye into a 20 per cent solution of common salt (i.e. at the rate of 20 lb. of salt dissolved in 10 gall. of water), when the ergots and light grains float to the surface and may be skimmed off. The sound corn should then be rinsed out with fresh water and spread out to dry.

Grasses which serve as hosts for the fungus should be kept down in the neighbourhood of rye crops, and when a field of rye has been infested, several years should elapse before the field is again sown with rye, or even wheat or barley, as these are occasionally attacked. Meadows in which the disease has been previously observed should be mown early to prevent the development of the ergots, and for a similar reason infected pastures should be cropped close.

Brown Rust.

The brown rust of rye, *Puccinia secalina* Grove, produces uredospores and teleutospores on rye, while the æcidial stage occurs on bugloss (*Anchusa arvensis*); it is therefore a heterœcious form. The uredospore stage appears early in summer on the leaves of rye as small brown spots; the uredospores are spherical and bear minute spines; they serve to spread the disease during the summer. They are succeeded by the two-celled teleutospores which form black spots on the under surface of the leaves; the teleutospores remain covered by the epidermis, and as soon as mature each gives rise to a promycelium and sporidia. The

latter are able to infect the bugloss, on which the cluster-cups (*æcidia*) usually appear in August or September of the same year. The æcidiospores germinate readily, and on reaching young rye leaves produce the uredospore stage within ten days.

Black Rust.

Puccinia graminis f. *Secalis*, a specialized form of the black rust fungus, occurs on rye, barley, and a number of wild grasses; it is similar in its morphology and life-history to the form on wheat.

Yellow Rust.

The specialized form, *Puccinia glumarum* f. *Secalis*, occurs on rye. (For further details see under Yellow Rust of Wheat, p. 321.)

Mildew.

A specialized form of *Erysiphe graminis* (see under Mildew of Wheat, p. 326) attacks rye.

INSECT ENEMIES OF GRAIN CROPS AND GRASSES

By R. STEWART MACDOUGALL, M.A., D.Sc.

Wireworms.

Wireworms are the larvæ or grubs of several different species of beetle belonging to the family Elateridæ. The beetles have four stages in their life-history, viz. adult, or stage for reproduction; egg; larva, or feeding stage; and pupa, or resting stage.

The adults are recognizable by the following characteristics: feet five-jointed; antennæ more or less saw-edged; hind corners of the joint behind the head more or less prolonged backwards; under surface of joint behind the head with a spine or process that fits into a cavity in the under surface of the next joint.

The larvæ or wireworms have elongated bodies, with flattened heads and chewing mouth parts; there are six legs in front, and on the under surface at the hind end a muscular process of service in locomotion. Behind the head twelve joints can be seen, and these have, on both upper and lower surface, horny shields, so that the grubs are hard to the touch. This horny covering is for protection, and the only time the body is soft is just before and after a moult (each larva moults several times in the course of its life); in the case of overcrowding, the grubs in their soft-bodied state may be preyed upon by their neighbours. There are slight differences in appearance, chiefly in the last joint, between the different species of wireworm. See fig. 1.

The four commonest troublesome Elater beetles are: *Agriotes obscurus*, *Agriotes lineatus*, *Agriotes sputator*, and *Athous hæmorrhoidalis*.

Wireworms are general plant feeders, not confining themselves, as so many insects do, to one kind of food plant or family of food plants, and this makes them more difficult to fight, as they cannot be dodged by altering the rotation. They are hardy but do not well resist drying or dry condition of soil, although they can do something to escape this by

going deeper into the soil; a certain amount of moisture is necessary for their life, and they can survive flooding for some days at any rate. They are difficult to starve, and can exist for a long time in soil that carries no crop.

The depth at which wireworms are found in the soil varies considerably—from a few inches to one or two feet—according to the nature of the soil, the weather conditions—dry, or wet, or frost—and the kind and depth of the crop plant. On the whole they are shallowest with permanent pasture, in agreement with the comparatively shallow-rooting grasses.

Life-history.—The adult beetles do no harm. They are found in the summer resting on flowers or crawling on the ground. The females lay their eggs in the soil, particularly about the roots of grass plants. Egg-laying is, probably, for the most part in June and July. The larva hatches, and has a long life in the soil in the larval or wireworm stage, viz. four years and perhaps sometimes five. When full grown the wireworm pupates in the soil, in an earthen cell or chamber, and in a month the adult beetles are ready to come to the surface to fly away and mate.

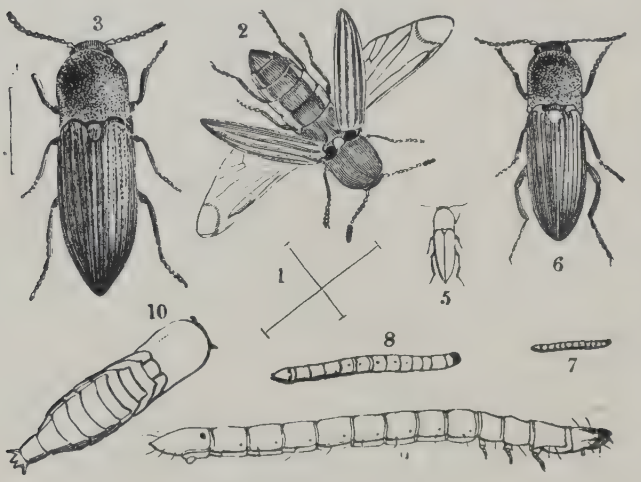

Fig. 1.—Wireworms

1 and 2, *Agriotes lineatus*. 3 and 4, *A. obscurus*. 5 and 6, *A. sputator*. 7, 8, and 9, Larva, natural size and magnified. 10, Pupa.

The characteristic place for the wireworms we are discussing is at and in among the roots of grasses in permanent pasture and wild grasses in neglected areas. The plants are crowded together, they are vigorous, they do not exhaust themselves by profuse seeding, and the damage caused by the wireworms does not show much. But when this is ploughed the succeeding crops may be expected to suffer. Similarly where in a rotation there are several years of temporary pasture followed by ploughing and a cereal crop, the young cereals are in great danger from wireworm.

The cultural measures that have an influence in keeping wireworm in check are the ploughing up as early as possible—the earlier the better—of grass land that has to carry a new crop, as the ground is in a firmer condition at seeding time. A firm compressed soil is not favourable to the egg-laying females. Leaflet 10 of the Board of Agriculture and Fisheries says: " If the land cannot be ploughed till the winter or spring, the turf should be broken up—for instance by disc-harrows—and then well buried. The greatest importance must be attached to the thorough

consolidation of the land, which in many cases is only attainable after the turf has been well broken up. A deep firm seed bed will often enable the subsequent crop to withstand a wireworm attack."

The rolling, in the case of young cereals, does something to prevent the larvæ from moving quickly from plant to plant. Spring, however, is a very busy time on the farm, and the constant rolling desired is not easy of attainment.

Young plants may be helped over the dangerous stage by forcing manures, such as nitrate of soda, but excess of nitrogen always causes lodging.

Gas-lime and salt have been recommended as dressings on the land before it is ploughed up, and considerably before the sowing of the crop, but sure experimental evidence is lacking. The same criticism applies to the use of rape-nuts, i.e. rape cake in the form of nuts used as a lure to keep the wireworms away from the crop plants.

A mustard crop has been sometimes recommended as a crop which will not be eaten by wireworms, and therefore of possible service as a crop on land infested with wireworm. Leaflet 10 of the Board of Agriculture and Fisheries says: "It is often supposed that mustard has some effect on wireworm, apart from causing starvation, and, in spite of statements to the contrary, this possibility cannot be neglected, for wireworms are most difficult to starve, and yet a mustard crop is sometimes effective in cleaning infested land".

In the United States there is often considerable loss of Indian corn "seed" due to wireworm attack. Mr. N. T. Fernald reported in the *Journal of Economic Entomology* a mode of treatment that proved satisfactory. "The seed was first tarred and placed in a bucket containing fine dust and Paris green (an arsenical poison) so mixed that the grains of Indian corn, after being shaken up in the bucket, had a greenish colour. The germination of the Indian corn was not interfered with, and the grain so treated was avoided by wireworms observed to be present." A considerable amount of experimental work has been done in the United States in effort to protect the seed by soaking in paraffin, chloride of lime, saturated solution of salt, but little or no success was got, and germination of such treated seeds was often spoiled.

Where the pest has been in destructive numbers, plough after harvest and again later to disturb the wireworms and bring them within reach of birds. The lapwing, the blackheaded and other gulls, the rook, the jackdaw, the starling, habitually destroy great numbers of wireworms; some other birds do so incidentally.

The Cockchafer (*Melolontha vulgaris*, fig. 2).

This beetle is harmful both as adult and as larva, the adults feeding on the leaves of various broad-leaved trees and the grubs on the

roots of plants, grass land and nurseries of young conifers suffering most.

The adult beetle can be recognized from the figure, the characteristic features being its size, the antennæ with fan-like expansions at their tip (seven in the male, six in the female), the black head and thorax, the red-brown hard wing-covers, and the downwardly curved somewhat pointed hind end.

Fig. 2.—The Cockchafer

Adult; larva and pupa of cockchafer; antenna closed and open.

The grub is six-legged, has biting jaws, and a curled, fleshy, wrinkled body whose last joint is swollen; the colour of the body is dirty white. Full grown, the grub measures over $1\frac{3}{4}$ in.

Life-history.—The complete life-cycle takes four years in a temperate climate like that of Britain. The adults pair in May and June. The fertilized females leave the trees and burrow into the soil to lay their yellowish eggs at a depth of 4 to 8 in. The eggs hatch in four or five weeks; the young larvæ grow slowly in their first summer, and feed, towards the surface, on young roots. In the autumn they go deeper for hibernation, to come to the surface again in the next spring to feed greedily on the underground parts of different plants, cereals, grasses, and garden and nursery plants. Hibernation follows in the second winter, with renewal of feeding in spring. In the third summer the larvæ may be full grown, and then, going deeper into the soil, pupation takes place, the adults issuing from the soil in the following May.

Fig. 3.—The Garden Chafer

Adult, natural size and magnified, and grub.

The Garden Chafer (*Phyllopertha horticola*, fig. 3).—This is a smaller beetle than the last. It measures $\frac{1}{3}$ in. long or slightly over; the head and thorax are glossy blue-green, and the wing-covers brown or red-brown; the body is hairy. The larva resembles in general that of the cockchafer, but is proportionately smaller, and as distinguishing features has the claws of the front pair of legs shorter than those of the second pair, and the claws of the second pair of legs shorter than the claws of the third pair of legs; further, the biting jaws of the garden chafer grub when magnified show a small

oval patch with file-like ridges running across them. The adults love sunshine, and eat the leaves of orchard and other trees, also the leaves and flowers of roses; and they gnaw fruits, e.g. apples.

The larvæ feed at the roots of grasses and of garden plants.

The life-history is completed in a year. The larva passes the winter as larva, and pupation is in late spring or early summer. I have several records of larval damage. In one case the grubs did great damage at the roots of a lawn of very old grass. In October the crows were observed tearing up the lawn to get the grubs, and again were at the same work in the following March. In another case the grubs were at work on old lea, attention being called to their work by the withered appearance of the grass and clover, the roots having been bitten through.

Treatment for Chafers.—Chafer grubs are difficult to reach, and they can continue to be harmful on permanent pasture where there is no ploughing up of the land with accompanying destruction of grubs.

Naphthalene is known to be distasteful to chafer grubs; it should be applied broadcast on affected areas at the rate of 2 cwt. per acre. The dressing can be given in autumn and in spring; if rain follows, the insecticide is carried into the soil.

At the swarming period of the adults—summer in the case of the garden chafer, and May in a swarm year of cockchafers — the adults should be shaken down on to cloths spread for the purpose of catching them, and then collected or swept together and destroyed. Experimentally, capture-gangs have had great success in this way.

Attempts have been made to destroy the grubs of the cockchafer by inoculation with a fungus, but experiments in the open proved disappointing. When infested grass land is ploughed up and the chafer grubs exposed, a number of birds take them greedily.

Moth Caterpillars.

The Antler or Grass Moth (*Charæas graminis*).—Periodically the caterpillars of this moth appear in overwhelming numbers. In the north of England 1824, 1827, 1881 were plague years; in the mountain districts of Wales 1884 and 1910; and in the hill pastures in the south of Scotland 1830, 1836, 1885, and 1894. In 1885 the upland pastures of Ettrick and Yarrow were greatly damaged by the grass moth caterpillars, and in 1894, over a very large area, extending from Roxburghshire right across to Ayrshire, hill pastures suffered severely. In the summer of 1917 caterpillars in some parts of the north and north-west of England were in such numbers as to choke up small rills and rivulets.

The antler moth measures over $1\frac{1}{4}$ in. in spread of wings. It gets the common name antler moth from the light-coloured branched line which, when the wings are extended, is seen to run from the body half-way

across each front wing. The general colour of the front wings is grey-brown or brown-grey; the hind wings are paler grey-brown. The full-grown caterpillar measures up to $1\frac{1}{4}$ in. in length; the body is round and the various joints well seen; the colour varies from dingy grey-brown to bronze-brown; under surface of body paler; along each side of the body runs a pale line; it has sixteen legs.

The moths are in flight in July, August, and into September, and they fly chiefly in the morning and forenoon. They drop their eggs among the grasses; the caterpillars hatch and pass the winter in shelter as partly grown caterpillars, coming out from their winter quarters in April and continuing their feeding till June. The full-grown caterpillar pupates in the soil.

Continental records from north Europe indicate that the caterpillars of the antler moth can be serious enemies to wheat, rye, and barley. British records, however, do not give exact account of damage to cereals. In consonance with the fact that the caterpillars frequent mountain and upland pasture and moorland, any list of attacked plants in Britain includes a number of the coarser grasses and also sedges and rushes. The late Mr. Service, who made observations of the antler moth plague in the south of Scotland, gives the following list of plants as most commonly attacked by the caterpillars: bent grass, mat grass, purple molinia, tussock grass, rough-stalked meadow grass, Yorkshire fog, deer's hair, cotton grass, sharp-flowered mountain rush, heath rush. Mr. Snell, of the Board of Agriculture and Fisheries, names as food plants, tussock grass, mat grass, sweet vernal grass, sheep's fescue, fiorin, species of Carex, heath rush, wood rush. Mr. Snell's list is more or less characteristic of the mountain, fell, and moorland—in the north-west of England—on which the caterpillars were at work, and which was ruined as feeding-ground for sheep during the summer.

Among the natural conditions which favour this insect, in any particular year or years, are the comparative scarcity of their bird enemies; persistent snow, under cover of which the hibernating caterpillars are protected; frost-bound ground. The burning of coarser mountain pasture growth at the end of March is a factor in the destruction of the caterpillars. Some warning is given of the likelihood of a plague by the impressive numbers of the flying moths seen in the preceding July and August. In such a case, with a following autumn or winter that favoured the caterpillars, trenches might be cut in the spring to trap the caterpillars. The caterpillars climb with difficulty, and have little power of overcoming obstacles.

The Common Rustic Moth, *Apamea* (*Hadena*) *didyma* (*oculea*). —This very common and very variable moth is scarcely mentioned in the economic literature. Curtis recorded it as injurious to wheat in 1846. Theobald, in 1905, recorded the caterpillars as destructive to

cock'sfoot grass in the experimental plots at Rothamsted. Carpenter recorded, in 1906 and 1907, injury to barley and oats. At Inveresk, near Edinburgh, and at Longniddry the caterpillars interfered with experiments that were being conducted by the Edinburgh and East of Scotland College of Agriculture by destroying barley, wheat, and oats.

The caterpillar is green, with the head yellow or light brown and glossy; two parallel brownish or purple-pink lines, separated by green, run along the back; the spiracles are bordered with black; there is a brown plate on the upper surface of the last joint; legs sixteen. The full-grown caterpillar measures about 1 in., and has the body somewhat narrowed at the front and hind ends.

The moths fly at night from the end of June onwards to August. They rest in the day-time chiefly among grass and herbage.

The caterpillars crawl up the stem of the cereal, and, choosing a leaf-sheath, gnaw their way down the stem under cover of the leaf-sheath. The stem is eaten through, and the developing leaf or leaves become yellow and come away very easily when pulled.

Attention is called to the work of the caterpillar by the leaf discoloration, the widening of the sheath of the leaf where the caterpillar is at work, the heap of excrement behind the tunnelling caterpillar, and by pieces of eaten-through shoots that have fallen out and are lying on the ground The caterpillars freely leave one destroyed plant and climb up and enter another. Curtis tells how three caterpillars destroyed in a fortnight upwards of thirty stems.

In some notes given to me by Mr. Thomas Anderson in connection with his East of Scotland experiments, Mr. Anderson wrote: "The wheat plot attacked by the caterpillars was sown from the two best ears of a plant reported in July, 1910, as the strongest plant in all the plots of that year. The germinative percentage was eighty-three. The plot was in 1911 the worst in tallness, uniformity, and density, the latest to ear, and, in all respects, the poorest of all the wheat plots."

Dipterous Enemies.

To the order Diptera, or two-winged insects, belong some of the severest enemies. Six of these call for mention here, viz. the daddy-long-legs, Hessian fly, wheat midge, gout fly, wheat bulb fly, frit fly.

The Daddy-long-legs (*Tipula*).—The sprawling, awkward-looking long-legged daddy adults are known as crane flies. They lay their eggs on the ground, pastures being favourite places. Lawns, cricket-fields, golf-courses, grass land, and clover also suffer from the ravages of the larvæ. The larvæ, known as leather-jackets from their tough outer skin, feed on many plants whose underground parts are not too hard, but the results of their attack are most conspicuous on grasses and

cereals, and especially on oats after clover or grass. It is in spring and early summer that most complaint is made. See fig. 4.

There are various species of daddy, varying in size and colour of body and wing. Two common species are *Tipula oleracea* and *Tipula paludosa*, but there are other troublesome species.

The larva of the crane fly or daddy—taking that of *T. oleracea* as the type—measures 1 in. and over in length when full grown. The colour is grey or grey-brown or earth-coloured. The head is black and horny, and can be withdrawn into the thorax; when it is thrust out the mouth-parts can be seen; by means of the strong mouth-parts roots are gnawed. The hind end of the body is blunt; the edge of the last joint has fleshy tubercles; the upper half of the hind face of the last joint is provided with two conspicuous breathing pores in the centre of the lower half of the hind joint.

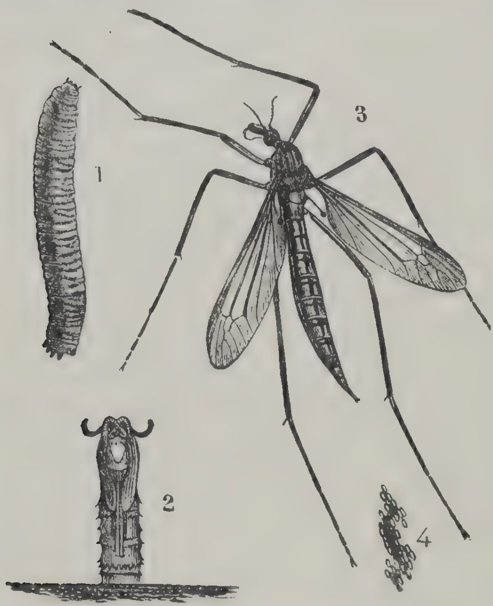

Fig. 4.—Daddy-long-legs

1, Larva. 2, Pupa. 3, Adult. 4, Eggs.

Life-history.—From the eggs laid in the ground larvæ hatch, and these live at the roots of plants. To begin with, the larvæ feed on humus and rotting plant matter in the soil, and later, on the live roots of young plants; or on the delicate shoots and leaves of seedlings, and occasionally on the seed itself.

The larvæ, hatched in summer and autumn, feed over the rest of the year and into the next spring, feeding nearer the surface when the weather is open and going deeper into the earth when frost comes. The larvæ of *T. oleracea* are most active from October to May.

The leather-jackets in the soil feed at the roots of plants or feed hidden or half-hidden in ploughed-in turf; but at night and in moist, muggy, sunless mornings they come to the surface and feed on young above-ground shoots and leaves. They can tunnel again into the soil at will.

When the leather-jacket is full grown it pupates in the soil. The pupa is spiny, and when the fly is ready to issue, the pupa, by means of the spines, wriggles to the surface and pushes itself half out of the ground; the adult fly escapes by a slit at the front end. In very bad daddy years lawns are sometimes brown with the standing-up pupa-cases.

How to fight the Daddy-long-legs.—Remember that grass and clover lea is practically certain to be used for egg-laying by Tipula, and the less close-grazed the pasture the greater the likelihood of its choice for the laying of the eggs. This is why it is sometimes recommended

to plough grass and clover lea in July. The reason underlying the advice is sound, and if it were possible to think only of the daddy the practice would be excellent. But in Scotland we cannot expect farmers to plough in July; the difficulties and disadvantages are too great. The alternative advice to this early ploughing, viz. the dressing of the land with gas-lime to kill eggs and young larvæ—good advice by itself—is also open to disadvantages, labour and others. There is no doubt that grass and clover lea will be chosen by the female for the laying of her eggs, and some warning that a succeeding crop may be likely to suffer from the "grub", as many call the leather-jacket, may be given in the preceding summer or late summer or autumn in the unusual numbers of crane flies. In such a case the roller, if applied at the proper time, is most useful; e.g. rolling on cold dull days, when the adults are sluggish and sheltering in the grass, will kill many. Rolling, in order to kill the grubs, should be in the evening or in the morning in sunless weather when the leather-jackets are on the surface. Even in a year when crane flies abound, weather may be against them, e.g. persistent gales.

There are conditions too which favour the leather-jacket. An important one is moisture. Various Tipula species show, by their choice of place for egg-laying, that a moist environment favours the leather-jacket. Rennie found in his experiments that lack of moisture caused a high mortality among his larvæ, and he quotes in relation to this the belief "held by some farmers that a wet summer and autumn foreshadows a plentiful supply of crane fly in the next year".

It has been stated above that the cereals are attacked when they are very young—at germination and following germination. The more drawn-out the young stage, because of weather, the greater the loss from the grub. Once the crop has made some progress it is safe. In a suspected year, then, a dressing of nitrate of soda applied in time may save the crop.

The chance that changeable weather conditions will not delay the development and growth of the young plants is part of the reason for the recommendation of late sowing (especially in a cold or late district), practised by the few, disliked by the many. Late sowing certainly carries risks with it as regards the harvest; but in leather-jacket years, in cold places liable to checks in spring, fields will be saved by the late sowing. No insecticide is known which would be practicable to apply on a field scale. Cost prevents the use of bisulphide of carbon as a fumigant. It is possible that naphthalene in some form may prove helpful. Dressings of salt are sometimes applied, but the evidence is conflicting; some are enthusiastic as to good results, others declare no benefit.

When the grubs are known to be at work in spring, harrowing should be done when the plants are about 3 in. high. The harrowing exposes the leather-jackets to birds; a heavy roller would kill many of them.

The Hessian Fly (*Cecidomyia destructor*).—This fly, the cause of great loss in the United States, was first recorded in Britain in 1886. Examples of its work were got from Inverness right to the south of England. Its host plants are wheat, barley, and rye. In other countries, with more favouring temperature and moisture conditions, there are several broods in the year, and severe loss may follow the laying of the eggs by the autumn brood of Hessian flies on autumn-sown wheat. In Britain, however, we escape this brood and the autumn egg-laying, and the Hessian fly is not so feared now as on its first being recorded.

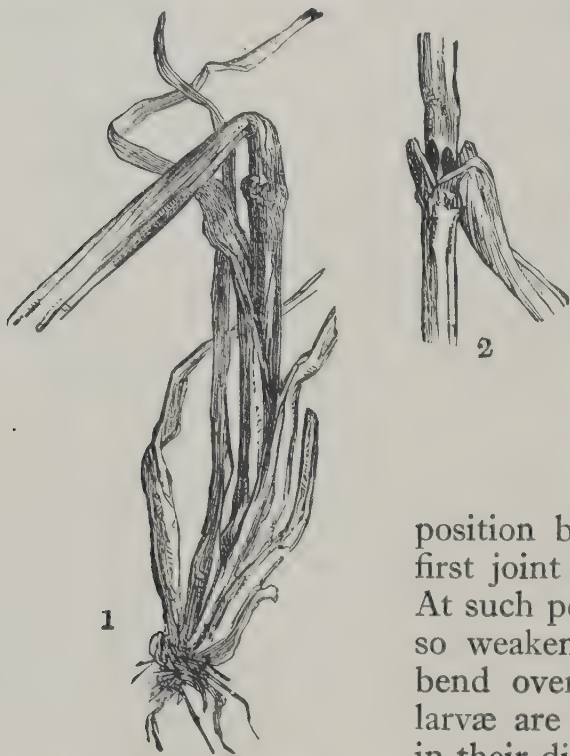

Fig. 5.—The Hessian Fly

1, Barley stem attacked by Hessian fly (straw bent). 2, Stem showing "flax seeds" in position.

The fly measures only $\frac{1}{10}$ in. in length and is black with a reddish tinge; the wings are hairy and are grey-black.

The females in May and June lay their eggs in small or larger groups on the upper surface of the young leaves of the cereal, between the veins. The larvæ soon hatch, and, moving head downwards, take up their position between the leaf-sheath and the stem, a favourite position being just above the second or the first joint or node from the base of the stem. At such points the sap is sucked and the stem so weakened that in bad attacks the stems bend over just above the place where the larvæ are situated. The larvæ vary slightly in their different stages, but in the later feeding stage the colour is yellowish white and shining; the skin under magnification shows little rough projections, and the length of the body is about $\frac{1}{8}$ in. Then, approaching a resting stage, the skin gets harder and becomes chestnut-brown, and this forms a shield or cover under which lies first the resting larva with its characteristic anchor plate, and then the pupa. Pupation takes place just where the larvæ have been stationed in their feeding, and the pupal cases look like flax-seeds.

If a crop has been attacked the "flax-seeds" will be left in the stubble after harvest. Such stubble should be deeply ploughed, so as to bury the pupæ beyond chance of the flies getting to the surface. Screenings that fall away in threshing should be swept together and burned, for the flax-seeds may also be numerous in such material. Parasitic insects help to keep this enemy in check.

The Wheat Midge (*Diplosis tritici*).—This minute yellow midge, with dark antennæ and eyes, lays its eggs in summer in the flowering heads of wheat; the eggs are inserted in little groups under the pales, by means of an ovipositor. The larvæ hatch in between a week and a fortnight, and their sucking, under cover of the pales, causes the ears to look a withered yellow and the grains to be stunted. The larvæ are golden-yellow, and have a characteristic anchor plate. The larvæ can be full fed in less than a month, when they leave the ears and go into the soil for pupation. Deep ploughing should follow an infestation of this midge to bury the pupæ. Pupæ can be found in the ears, but it has been pointed out that these are parasitized and their position in the ear is abnormal. If this observation could be relied on as a constant happening, then the destruction of the screenings would not be a measure to be recommended on account of the consequent destruction of the useful parasitic enemies of the midge.

Clinodiplosis aurantiaca.—This is an orange-yellow midge which, like the last, lays its eggs in the ears of wheat and sometimes rye. The larvæ are orange-yellow or orange-red.

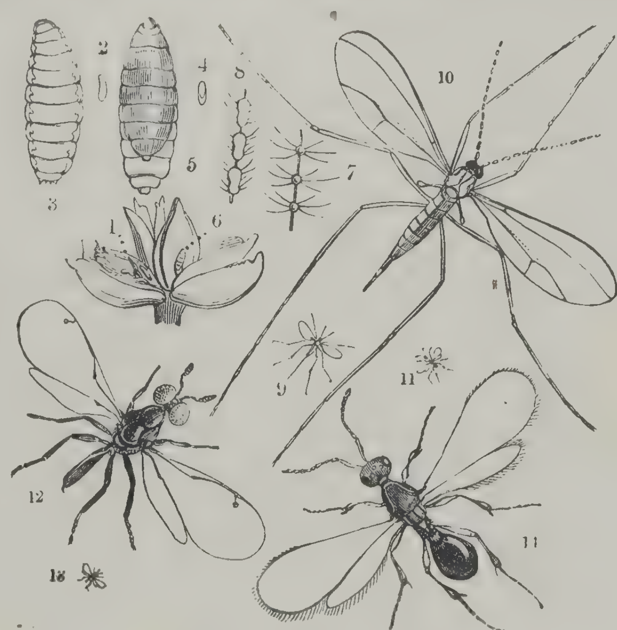

Fig. 6.—The Wheat Midge

1 and 6, Infested floret. 2 and 3, Larvæ. 4 and 5, Pupæ. 7 and 8, Part of antenna. 9 and 10, Adult. 11–14, Parasitic insects.

Clinodiplosis equestris.—This species is red in colour with yellow hairs. It has wheat as its host plant, and is sometimes confused with the Hessian fly. It differs, however, in a number of ways. Apart from distinct differences in appearance between the adult flies, the larvæ are red and attain a length of $\frac{1}{5}$ in.; the eggs are laid a little earlier in the year; the larvæ feed under cover of the leaf-sheath of the upper nodes rather than on the lower; the position of the feeding larva is characterized by saddle-like swellings and wounds on the culm; the leaf-sheaths are inflated at these areas. The parts of the plant above the attacked areas are stunted and poor. The larvæ are full grown about the time of the ripening of the wheat, when they leave the plant and go into the soil for pupation.

The Gout Fly (*Chlorops tæniopus*).—This fly is an enemy of wheat, barley, and rye, but its worst attacks are on barley.

The ears of the weakened plants injured by the larvæ fail to burst

out from the surrounding leaf-sheaths, and it is from the resulting swollen appearance that the fly gets its common name. Drought favours the fly and checks the plant, and it is thus in seasons of drought that the heaviest losses are recorded.

The fly, only about $\frac{1}{6}$ in. long, needs magnification to bring out its points. Yellow is the prevailing colour, with a dark triangle on the head, dark longitudinal lines on the thorax, and dark transverse lines on the abdomen; the antennæ are dark, and the eyes green.

The larva is a legless maggot, white or yellow-white in colour, with two mouth-hooks in front and two spiracles on the hind face of the last joint.

Fig. 7.—Gout Fly

1, Furrowed stem. 2 and 3, Fly, natural size and magnified. 4, Larva. 5, 6, and 11, Pupæ. 7–10, Parasites, natural size and magnified.

In May and June the flies lay their eggs on the leaves enclosing the ears. The larvæ make a channel with their mouth-hooks from the base of the ear downwards to the first node. Pupation takes place at the end of the channel or among the ensheathing leaves. The new brood issues from August onwards, and the females of this brood lay on wild grasses, and it may also be on newly sown wheat or winter barley.

Treatment.—Sow wheat as late as possible in autumn, and barley as early as possible in spring. Burn the refuse after threshing a crop which has been infested.

The Wheat Bulb Fly (*Leptohylemyia* or *Hylemyia coarctata*).—This fly belongs to the family Anthomydiæ; it is a greyish-yellow fly, very hairy or bristly; the narrow, flat abdomen has a dark line running down the middle of the back. The larva often proves very destructive to young wheat, the larva living in and feeding on the very heart of the young plant. A larva can, after destroying one shoot, enter and destroy others. The larva, apart from its characteristic position in the young plant, is quite easily distinguishable from the other larvæ already mentioned. When full grown it measures about $\frac{1}{3}$ in.; the somewhat pointed head end is furnished with two dark mouth-hooks; behind the head is a pair of fan-shaped spiracles with nine divisions to each; on the hind face of the last joint are two spiracles; on the lower edge of this joint in the

middle line are two easily seen projections, each of which is two-pronged; to the outside of each of the large projections is a small tooth.

Periodically the attacks are very severe, the last being in the spring of 1920, when a great deal of damage was done to young wheat in Midlothian, West Lothian, Fife, and Forfarshire. Writing to Mr. F. R. Petherbridge, Cambridge, Mr. F. Hiam, a farmer in the Fen district, said: " The wheat bulb fly does not appear to do much harm in a wet, cold, or damp summer, but during a dry summer, say from 20th July to 29th September, on all bare lands—namely fallows, early potato land, or late potatoes, mangolds, and swedes—where there is not sufficient top to keep the sun from the land, the bulb fly will deposit her eggs, and, if wheat is sown, it is sure to be practically spoilt when the eggs hatch in spring. On wet land, or in a wet season, the eggs do not seem to mature. Should the fallow be clear by the end of July, mustard or rape seed could be drilled and then ploughed in for the wheat crop. The same applies to land cleared of early potatoes."

It is well known that infestation is worst after bare fallow, and worse after potatoes than after turnips, worse after early potatoes than late—in a word, worse where the soil is bare or exposed during the summer.

Professor Gemmill has found the eggs in the field chiefly in bare soil and in potato fields; no eggs hatched in nature before the middle of February. He has found rye and couch also infected, and this bears out the old suggestion that couch was the likely wild grass to act as the host plant.

Mr. F. R. Petherbridge bred out the adult flies, in the laboratory, from infested wheat, and these flies were placed in a jar with sifted soil in the bottom, where the females were observed to lay eggs, " the ovipositor being inserted to its full length in the soil ". In another experiment where sterilized soil was used one part was left bare, one part had ryegrass transplanted in it, and the remaining middle portion had wheat sown on it. The females laid eggs on the bare fallow and in the loose soil between the wheat plants. As far as observation goes at present, the likeliest life-cycle is an annual one (one generation in the year, though two are known in middle Europe), the flies appearing in June and July, and the eggs laid then and later remain over the winter to hatch in the next February. Still there must be variations, for we have taken the larva in the south in dying young wheat in November and December.

The Frit Fly (Oscinis or *Oscinella frit*).—This is one of the chief cereal pests of Europe, oats, barley, rye, wheat, maize, and various grasses acting as host plants. The chief damage in Britain is to oats. There are two main types of damage: first, the damage to the young plants, revealing itself in May and at its height in June and to mid-July; and the damage to the young grain in the ears, from the second brood of the

year, in July and August. In September, 1904, a case was recorded from Sussex where actually 80 per cent of the grain was infested. It had been the opinion in Britain that this attack in the young ears of oats was not common; we know now that there may be considerable loss in grain from such attack.

The fly measures less than $\frac{1}{8}$ in.; the body is black. The larva is a legless maggot measuring when full grown and extended $\frac{1}{8}$ in.; at the head end are two mouth-hooks, by which the leaf-sheath can be penetrated, or a young leaf gnawed across, or a young developing grain pierced; at the hind end are two small but distinct projections by which air is taken in. The larva is pale yellow to yellow-brown, and, when young and in the very heart of a young oat plant, has to be looked for carefully. The puparium, under cover of which pupation takes place, is brown-yellow, narrowing at the hind end where the two projections are evident.

Three generations, at any rate, are possible in Britain in a year. The first flies of the year lay their eggs on the young plants in May, and in this month and in June the stunted growth and the yellow-brown central leaves call attention to the attack. The larva on hatching passes to the apex of the young shoot and the shoot is destroyed. Whether such an attacked plant continues to grow depends on the success of tillers and the healthiness of the adventitious roots. Pupation takes place where the larvæ have been feeding, and the flies of the new brood come away in due course. The second brood of flies can be at their egg-laying in July and in August, the eggs being laid on cereals, pasture and wild grasses, and in the young ears of oat. The grain in such cases is light and shrivelled. Another brood comes away in autumn, and grasses are used for the reception of the eggs. Overlapping is possible between the generations.

If the maggot has got to work in the heart of the young plant, or protected in the ears, it is safe from treatment. Early sowing of oats, so as to get the plants as well forward as possible before the onset of the fly, has sufficient experimental evidence behind it to justify the advice. Any success against frit must be in connection with cultural methods.

Aphis and Thrips.

The Grain Aphis (*Macrosiphum granarium*).—This aphid has for its host plants species of the order Gramineæ. Wheat and oats are sometimes very badly infested, swarms of the aphid being found in the earlier part of the year on stems and leaves and later also in the inflorescences. Macrosiphum feeds by inserting its sucking mouth-parts into the tissue and then drawing away the sap. The result may be shrivelled grains or no grains at all.

In favourable weather conditions these insects multiply with great

rapidity, and throughout the year different individuals belonging to various generations may be found, viz. wingless virgin females that produce live young; winged virgin females that can migrate to other plants, and able also to produce live young; winged males; winged sexual egg-laying females. Towards the end of the season males are found and pairing takes place (for the only time in the year's life-cycle). A fertilized egg is laid, which in the next spring hatches out into a young aphid, which soon becomes adult and is the foundress of the succeeding virgin female generations.

Fig. 8.—1–4, Corn Thrips (*Thrips cerealium*, natural size and magnified

Thrips.—The various species of thrips are very minute insects, with elongated bodies and four fringed wings; the legs end not in claws but in suckers or bladders. The mouth-parts are fitted for breaking and tearing the outer tissue of the stem, leaf, and flower parts, and young developing grain. The sap that exudes from these wounds is lapped up by the thrips, and, if the drain on the attacked part is severe enough, the tissue shrinks and curls and bleaches. Damage to cereals and to grain is done by a thrips both in the adult and larval stages.

The life-history is simple. The adults lay their eggs on the host plant. Larvæ hatch which are wingless; they move about in their feeding, until at last a resting non-feeding stage is reached, characterized by four short wing-cases. Certain changes take place, and the active winged adult stage is attained.

INSECT ENEMIES OF BEANS AND PEAS

The Bean Aphis (*Aphis rumicis*, **L.**).—In some seasons this aphis is a perfect scourge in field and garden beans. From the fact that crowds of this dark-coloured aphid often give the bean shoots the appearance of being covered with soot, a common name for the insect is the Collier or Black Fly.

This aphid feeds in one or other of its stages on a large number of totally distinct plants. The life-history is complex, not being completed on a single plant; migrations from one plant to another species of plant take place. Only once in the course of the year, namely towards and in autumn, are sexual males and females found. These pair, and fertilized eggs are laid. The eggs remain unhatched over winter, and in the next spring females develop from the young that have then hatched. During spring and summer a number of virgin female generations are produced, some of them wingless, some winged.

A number of points in the life-history that were obscure have been cleared up by the observations and experimental work of Theobald and Davidson.

Theobald showed that there were two possible and, as it seemed, separate life-cycles of *A. rumicis*, which here we shall name A and B.

In A eggs which had overwintered on the spindle tree (Euonymus) hatched in spring and gave rise to adult females, which were the progenitors of a migrant generation of winged females which flew to poppies and to mangolds and beet; in autumn descendants of these migrated to the spindle tree and gave rise, in late autumn, to a generation of males and females. After pairing, fertilized eggs were laid on the spindle tree, and in this egg stage the winter was passed.

Fig. 9.—Bean Aphis

1, Infested bean shoot. 2 and 3, Winged male. 4, Wingless female, magnified.

In B eggs which had overwintered on dock hatched in spring and gave rise to adult females, the progenitors of a migrant generation of winged females which flew to beans and gave rise on the bean to generations of bean aphides. In autumn a migration took place from bean to dock. This migrant generation gave rise, in late autumn, to a generation of males and females. After pairing, fertilized eggs were laid on the dock, and in this egg stage the winter was passed.

Davidson proved that these two cycles are not mutually exclusive, but that migrants from spindle tree will pass to and multiply on bean, and that the aphid on the spindle tree placed experimentally on dock will migrate to and multiply on beans and poppy.

Thistles are also possible host plants for *A. rumicis*.

The result of this attack on beans is a greatly lessened yield or even the destruction of the crop. The wisest thing to do is to watch for the first sign of attack in early summer and to cut off and destroy the infested tops. A spray to use at this time is soft soap and quassia.

Dissolve 5 lb. soft soap in 100 gall. of soft water, boil 6 to 8 lb. of quassia chips in water, and add the extract to the 100 gall. of wash.

The Bean Beetle (*Bruchus rufimanus*) and **The Pea Beetle** (*Bruchus pisi*).—These two beetle are injurious to in one case the seed of the bean, and in the other the seed of the pea. While damage by the adult beetles to the foliage of young plants has been recorded, it is the larva or grub which is the chief enemy. The grubs live in and feed on the seeds.

The two beetles are tiny, measuring about $\frac{1}{6}$ in. in length; they are oblong in shape and dark in ground colour, with a fine covering of brown or brown-grey hairs. The wing-covers are rather short, so that the hind part of the abdomen is exposed; the hind legs are longer than the other legs.

The two beetles are very like one another, but the bean beetle can be distinguished by the red thighs of the front pair of legs; further, the exposed tip of the abdomen of the pea beetle has two dark spots on it, while in the bean beetle the exposed tip is covered with white-grey pubescence, and there are no dark sports or at most they are very faint.

The grubs are whitish yellow in colour, fat, and wrinkled; the head is furnished with gnawing mouth-parts, and legs are absent, though at first on hatching three pairs of very minute legs are visible.

The adult beetles lay their eggs, in the open fields, on the very young pods. The grubs on hatching bore into the bean seed or the peas and nourish themselves in the seed. The full-fed grub pupates in the seed, and in the next spring or earlier, according to the temperature, the adult emerges.

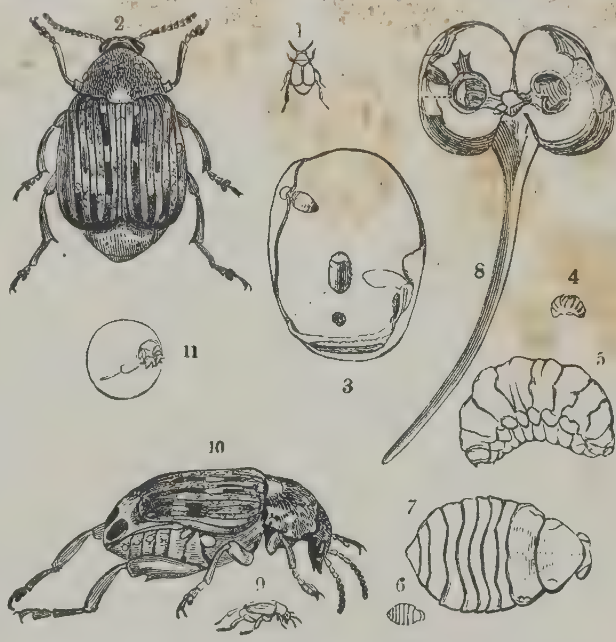

Fig. 10.—Bean and Pea Beetles

1 and 2, Bean beetle, natural size and magnified. 3, Attacked bean. 4 and 5, Larva. 6 and 7, Pupa, natural size and magnified. 8, Seedling from attacked bean. 9 and 10, Pea beetles. 11, Attacked pea.

Infested beans or peas should not be sown. That they are infested is indicated by a small circular patch on the outer skin, under which the beetle lies.

The pests in the bean or pea can be killed by fumigating with bisulphide of carbon. The beans or peas for treatment are placed in an air-tight bin or receptacle. Bisulphide of carbon is poured into a shallow saucer or saucers, and these are placed *on the top* of the enclosed seed. Bisulphide of carbon vaporizes readily, and the vapour—heavier than air—sinks down through the seed and poisons grubs, pupæ, and beetles. The material undergoing treatment should remain for forty-eight hours. Two pounds of bisulphide of carbon is the quantity for 1000 c. ft. of air space. The fumigation should be done at 70° to 75° F.

The bisulphide of carbon vapour is explosive and easily inflammable, therefore no naked light should be present or brought near. The operator should not remain in the vapour.

Pea and Bean Weevils—These weevils belong to the genus Sitones. The best-known Sitones is *S. lineatus*, which, in addition to its attacking peas and beans, is also destructive to clover and vetches. The length of this weevil is about $\frac{1}{4}$ in.; the dark-coloured body is covered with greyish scales; there are three grey or grey-green lines down the thorax, and there are alternate dark and light lines on the wing-covers. When the beetles are disturbed, say on the plants being jarred, they fall to the ground, and are, especially when lying on their backs, very difficult to detect. The larva is a small, legless, wrinkled grub, with brown head and jaws.

This weevil is injurious both as adult and as grub. The adults eat notch-like pieces out of the leaves, beginning at the edge and eating round to the edge again, and they also completely destroy young shoots. The grubs live in the soil at the roots of the plant and destroy the root nodules.

The beetles pass the winter in the adult stage, hibernating in hedgerows, long grass, stubble of clover fields, &c. In spring they issue from these shelter-places and do great damage to the young plants, which are in their tender susceptible state. Eggs are laid in May at the bases of the plants; they need moisture for hatching. Miss Dorothy Jackson, who has worked out the details of the life-history, states that the eggs hatch in twenty to twenty-one days, that the grub is full fed in six to seven weeks, and that the pupal stage, passed in the soil, lasts for three weeks. The new generation of beetles comes away from August onwards. These new beetles do not breed in the season of their appearance above ground, but feed and then hibernate.

Where the conditions are suitable, roll the peas and beans with a light wooden roller to break up clods, to consolidate the soil round the plants, and to destroy shelter-places; then dress the plants with soot when they are wet with dew.

Pea and Bean Thrips (*Thrips pisivora*).—This is a very minute insect, measuring at most only up to $\frac{1}{12}$ in. in size. The adult insect has four somewhat long and narrow wings, the wings being provided with distinct fringes. The larval thrips is orange-yellow in colour and wingless.

Eggs are laid in the young blossom, and the larvæ, on hatching, by their wounding and sucking mouth-parts cause the flowers to shrivel. The pods fail to fill and curl up and become rusty.

The Pea Midge (*Diplosis pisi*) and **The Pea Leaf and Shoot Miner** (Agromyza).—These two flies have been recorded in England as harmful. The larvæ of the Pea Midge live in the pod, which, as a result, becomes short and swollen; the seeds are not attacked. The larvæ of the Miner eat out galleries in the middle soft tissue of pea leaves and also mine the shoots. When the mines are numerous the assimilating

and feeding leaf area is so reduced that flowering and the production of seeds is impossible.

The Pea Moth (*Endopisa nigricana*).—This moth is found over Britain up to Perthshire. The moth measures $\frac{1}{2}$ to $\frac{5}{8}$ in. in spread of wings. The front wings are glossy dark brown to black with white streaks at the fore edge; a curved white streak shows near the hind edge about the middle of the wing; the fringes of the front wings have the same ground colour. The hind wings are brown with white fringes.

Fig. 11.—Pea Moth

1 and 2, Larva, natural size and magnified. 3 and 4, Moth, natural size and magnified.

The caterpillar when full grown is $\frac{1}{3}$ in. long. The colour is very pale green or yellowish white with the head dark; the joint behind the head has a horny plate; there are dark dots or warts over the surface of the skin, each wart carrying a bristle; there are sixteen legs.

It is the caterpillar which does the damage; it lives and completes its growth inside the pod, gnawing and destroying the peas.

The moths are found in flight from June to August. The females lay their eggs on the young pods. The caterpillar on hatching enters the pod and makes its way to the peas. When full-fed the caterpillar leaves the pod and enters the soil for pupation.

The damage by this caterpillar is sometimes confused with that of the Pea Beetle (Bruchus). Elsewhere I have pointed out how these two enemies of the pea can be distinguished:

Larva of Pea Moth.	Larva of Pea Beetle.
A caterpillar with sixteen legs. Pupa in soil. The peas are irregularly gnawed externally. The attacked peas are often woven together by silk threads, and there is a distinct granular excrement.	A legless grub. Pupa in pea. The peas are gnawed internally. There is no sign of spun threads, and the hollowed-out peas appear clean, without external excrement.

The only time when the pea moth brings itself within reach of treatment is when in the caterpillar or pupal condition in the soil. A thorough hoeing after the land has been cleared of peas would expose and kill caterpillars.

If attack has been on a wide scale, deep ploughing before winter will bury the caterpillars so that, even in case of pupation, the moth cannot get up to the open. This is a simple and at the same time a very

effective method of dealing with the pests under field conditions. To ensure their destruction, however, the ploughing must always be sufficiently deep.

In garden practice, the haulm, in the case of an attack, should be gathered and burned. This precautionary measure can also be taken in the case of field crops of "picking" peas.

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